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GTS *Callaghan*/C-141 VLF/LF Data 1984 - 1986

Computer Sciences Corporation

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This report discusses VLF/LF signal data collected on: (1) the GTS *Callaghan*, a Military Sealift Command (MSC) cargo ship and (2) Military Airlift Command (MAC) C-141 aircraft. It describes the VLF/LF transmitters monitored, the navigational tracks used by the two types of collection platforms, the data acquisition systems, calibration procedures and the resulting normalized signal data. Near field radiated power measurements, measured noise levels, and the overall accuracy of the VLF/LF signal data collected are also discussed.

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TABLE OF CONTENTS

	Page
SECTION 1 - INTRODUCTION	1
1.1 VLF/LF Transmitters Monitored	1
1.2 Navigational Tracks	4
SECTION 2 - RECORDING EQUIPMENT USED	11
2.1 HP 3586C Selective Level Meter	11
2.2 VHF Switch	11
2.3 HP 85/87 Computers	13
2.4 HP 9121D Disc Drive	13
2.5 Preamplifier	13
SECTION 3 - RECORDED DATA TYPES	15
SECTION 4 - CALIBRATION PROCEDURES AND RESULTS	18
4.1 Field Calibration Equipment	18
4.1.1 Sierra 127C Frequency Selective Voltmeter	19
4.1.2 Briefcase Loop Antenna	19
4.2 Calibration Sites	19
4.2.1 GTS Callaghan Calibration	22
4.2.2 C-141 Aircraft Calibration	22
4.3 Calibration Results	27
SECTION 5 - NORMALIZED VLF/LF DATA	34
SECTION 6 - RADIATED POWER MEASUREMENTS	38
6.1 Radiated Power Calculations from Callaghan Data	38
6.2 Radiated Power Calculations from C-141 Data	42
SECTION 7 - SIMULTANEOUS AIRCRAFT/SHIP DATA	47
SECTION 8 - PROBLEMS ENCOUNTERED DURING THE PROJECT	53
8.1 Antenna Failure	53
8.2 Preamplifier Difficulties	53
8.2.1 Unstable Calibration Circuits	53
8.2.2 Observed LF Signal Distortion	55
8.2.3 Preamplifier Thermal Noise Limitations	58
SECTION 9 - ACCURACY OF VLF/LF C-141 AND CALLAGHAN DATA	66
REFERENCES	67

APPENDICES

APPENDIX A: GTS CALLAGHAN AND C-141 NAVIGATION TRACKS A-1

APPENDIX B: PREAMPLIFIER FREQUENCY RESPONSE CURVES B-1

APPENDIX C: LOG DISTANCE PLOTS USED TO CALCULATE RADIATED POWER C-1

APPENDIX D: SIMULTANEOUS C-141 AND CALLAGHAN VLF/LF SIGNAL DATA D-1

APPENDIX E: CALLAGHAN PREAMP CALIBRATION STABILITY PLOTS E-1

APPENDIX F: VLF/LF NOISE DATA F-1

F.1: GTS Callaghan Noise Data F-2
F.2: C-141 Noise Data F-40

APPENDIX G: C-141 VLF/LF SIGNAL DATA G-1

APPENDIX H: GTS CALLAGHAN VLF/LF SIGNAL DATA H-1

LIST OF ILLUSTRATIONS

Figure		Page
1.1	Location of VLF/LF transmitters monitored by the GTS Callaghan and C-141 aircraft during 1984 and 1985	2
1.2	Example of navigational tracks of the GTS Callaghan during cruises 1-3.	9
1.3	Example of navigational tracks used during 3 consecutive September, 1985 C-141 flights	10
2.1	System diagram of the VLF/LF recording equipment used on the GTS Callaghan	12
2.2	VLF/LF whip preamplifier circuit diagram	14
3.1	GTS Callaghan signal/spectrum data at 21.4 kHz, recorded 10/01/85	17
3.2	C-141 spectra at 88.0 kHz, recorded 9/21/85	17
4.1	Sierra 127C VLF/LF calibration system diagram	18
4.1.1	Circuit diagram and component layout of the VLF/LF calibration preamplifier	20
4.2	Briefcase loop 1 calibration correction factor curve	21
4.3	Calibration locations visited in Bayonne, NJ to calibrate the GTS Callaghan	23
4.4	Calibration locations visited in Charleston, SC to calibrate the GTS Callaghan	24
4.5	Effect of attitude on C-141 VLF/LF signal data	25
4.6	Calibration factor curve for preamp 2 with a 6 foot whip antenna. This curve applies to data recorded during cruises 1 to 9	29
4.7	Calibration factor curve for preamp 2 after about 1/2 of the original 6 foot antenna broke off. This curve applies to data recorded during cruises 10 to 16	30
4.8	Calibration factor curve for preamp 1 and its 8 foot whip antenna. This curve applies to data recorded during cruises 17 to 23	31
4.9	Calibration factor curve for preamp 8 and its 8 foot whip antenna. This curve applies to data recorded during cruises 24 to 52	32
4.10	Calibration factor curve for C-141 flights where the hatch blade antenna and preamplifier serial #3 were used	33
5.1	VLF/LF data at 21.4 kHz (Annapolis, MD) as measured from the GTS Callaghan.	36
5.2	VLF/LF data at 21.4 kHz (Annapolis, MD) as measured during C-141 flight 3	37
6.1	Log distance plot for cruise 8, used to calculate the radiated power for Thurso, Scotland at 55.5 kHz	39
6.2	Near field radiated power measurements of Thurso, at 55.5 kHz. Measured 6/20/84	40
6.3	Log distance plot, flight 3 - Frankfurt to Andrews. Used to determine radiated power for Rugby, England at 16.0 kHz	43
7.1	Navigational tracks used by the GTS Callaghan (cruise 20) and C-141 aircraft (flight 2)	48
7.2	Navigational tracks used by the GTS Callaghan (cruise 20) and C-141 aircraft (flight 3)	49
7.3	Simultaneous VLF/LF signal data collected on the GTS Callaghan (cruise 20) and C-141 aircraft (flight 2). The frequency monitored was located at Rugby, England, and was broadcasting at 16.0 kHz	50
7.4	NOSC propagation prediction curve for 16.0 kHz along the path from Rugby, England to the nearest approach of the Callaghan and C-141 aircraft (September, 1985 flight 2)	51

8.1 Calibration variations for Callaghan preamp #2 54
8.2 C-141 preamplifier saturation near Europe for preamp #3 56
8.3 GTS Callaghan preamplifier saturation near Europe for preamp #2 . 57
8.4 VLF/LF preamplifier noise floor, in dBV, for preamplifier serial number 8 59
8.5 Callaghan noise data at 26.0 kHz, cruise #1 60
8.6 Measured noise level at 63.0 kHz during GTS Callaghan cruise 17 . 63
8.7 C-141 noise data during flight 3 (1985), at 26.0 kHz 64
8.8 C-141 noise data during flight 8 (1985), at 63.0 kHz 65

LIST OF TABLES

Table		Page
1.1	VLF/LF frequencies recorded on the GTS Callaghan and C-141 MAC aircraft flights	3
1.2	Noise channels monitored on the GTS Callaghan and C-141 aircraft	4
1.3	GTS Callaghan cruises 1 to 30	5
1.4	GTS Callaghan cruises 31 to 52	6
1.5	Approximate location of the major harbors visited by the Callaghan	6
1.6	Origin, destination, takeoff, and landing time for June, 1984, C-141 flights	7
1.7	Origin, destination, takeoff, and landing time for February, 1985, C-141 flights	7
1.8	Origin, destination, takeoff, and landing time for September, 1985, C-141 flights	8
4.1	Sierra 127C Specifications	19
4.2	Date, location, and preamp serial number used for calibrations, the primary reason for the calibration, and the cruise numbers for which the calibration applies	26
4.3	Date and location of C-141 calibrations	26
4.4	Average takeoff and landing effects on VLF/LF relative voltage levels as measured on C-141 aircraft during June, 1984	26
6.1	Radiated power for Thurso, Scotland at 55.5 kHz as measured from the GTS Callaghan	41
6.2	Radiated power deduced from field strength measurements made on the GTS Callaghan during close approaches to VLF/LF transmitters on the East coast of the US	42
6.3	VLF radiated power measurements deduced from C-141 flight data	44
6.4	LF radiated power measurements deduced from C-141 flight data	45
6.5	Comparison of radiated power measurements made on the Callaghan verses measurements made on C-141 aircraft	46
7.1	Simultaneous Callaghan and C-141 signal data: Cruise 20, flight 2	52
7.2	Simultaneous Callaghan and C-141 signal data: Cruise 20, flight 3	52
8.1	NOSC VLF/LF preamplifier thermal noise lower limits in dB/uV/m for a 400 Hz bandwidth	58

SECTION 1 - INTRODUCTION

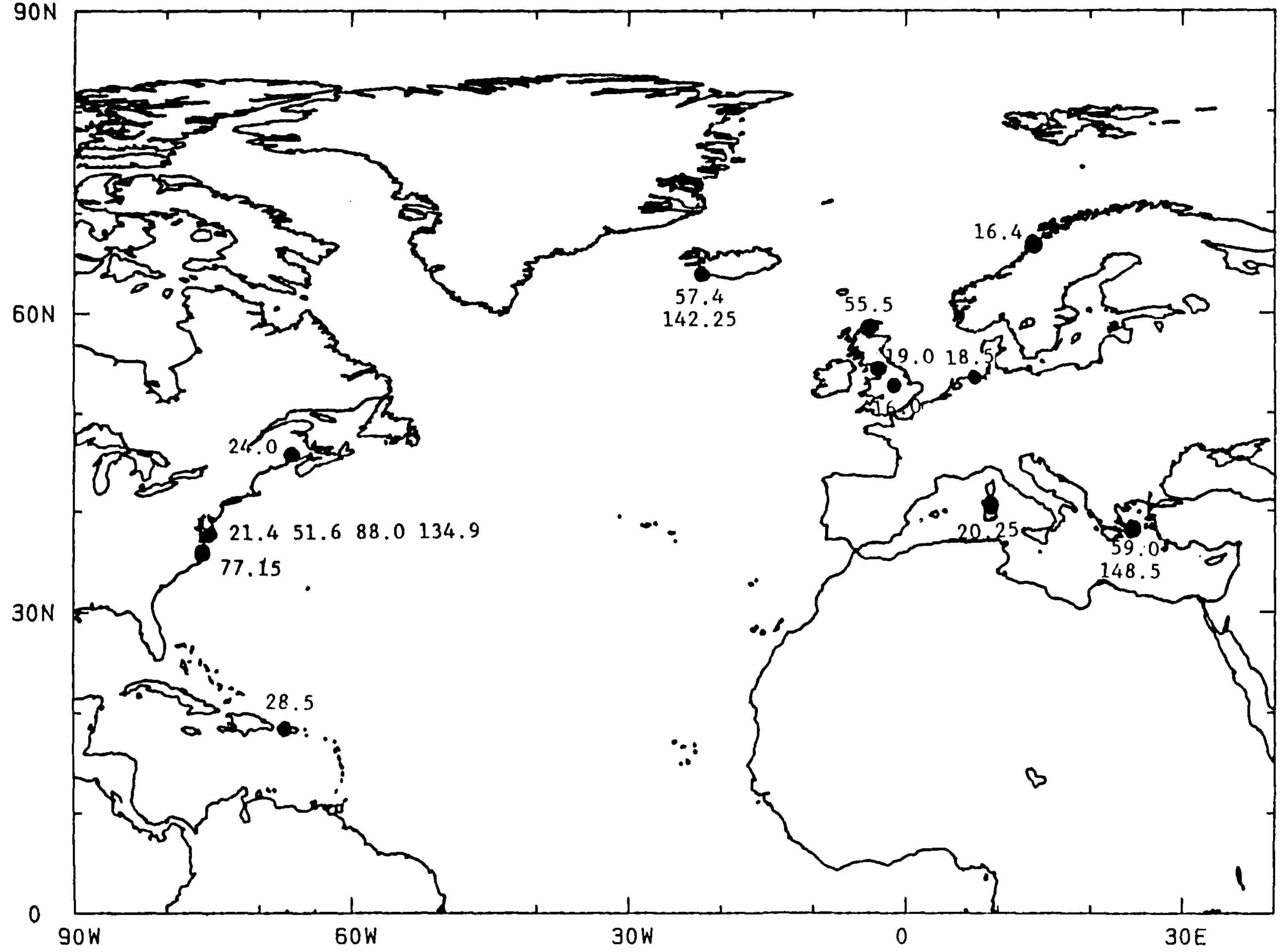
This report discusses VLF/LF signal data collected on: 1) the GTS Callaghan, a Military Sealift Command (MSC) cargo ship (March 29, 1985 to April 4 26, 1986); and 2) Military Airlift Command (MAC) C-141 aircraft during June, 1984, February, 1985, and September, 1985. It describes the VLF/LF transmitters monitored, the navigational tracks used by the two types of collection platforms, the data acquisition systems, calibration procedures, and the resulting normalized signal data. Near field radiated power measurements, measured noise levels, and the overall accuracy of the VLF/LF signal data collected are also discussed.

1.1 VLF/LF Transmitters Monitored

During the course of this project 20 VLF/LF transmitters were monitored during cruises across the Atlantic to study propagation phenomenon over a wide range of frequencies. The transmitters monitored ranged from the east coast of the United States to transmitters located in Europe, the Mediterranean, and Australia. Figure 1.1 illustrates the location of most of the VLF/LF transmitters monitored during this project.

The recording systems used on the Callaghan and C-141 aircraft are capable of monitoring up to 20 separate frequencies. Typically, 14 to 15 VLF/LF transmitters are monitored during a cruise or flight, with two additional frequencies monitored that do not have transmitting stations assigned to them. These two frequencies are monitored to measure atmospheric noise (ideally) or the noise level of the system, as well as to determine the signal to noise ratio for the signal data collected from active transmitters. Table 1.1 lists the VLF/LF transmitters monitored, the location of each transmitter, and the time period for which each transmitter was monitored during Callaghan cruises and C-141 flights. Table 1.2 lists the noise channels monitored.

Figure 1.1 Location of VLF/LF transmitters monitored by the GTS Callaghan and C-141 aircraft during 1984 and 1985.



VLF/LF Frequencies Recorded on the
GTS Callaghan and MAC Aircraft Flights

Freq (kHz)	Station	Position				Aircraft			Ship			
		Latitude		Longitude		6/84	2/85	9/85	3/07/85–7/01/85	7/01/85 9/08/85	9/08/85–10/18/85	10/18/85 4/26/86
		DEG.	MIN.	DEG.	MIN.							
16.0	Rugby	52	22.2'N	01	11.2'W	X	X	X	X	X	X	X
16.4	Novik	66	58.5'N	13	53.0'E		X	X	X		X	X
17.8	Cutler	44	39.0'N	67	16.9'W			X			X	
18.5	Rhauderfehn	53	06.0'N	07	35.0'E			X			X	X
19.0	Anthorn	54	54.9'N	03	16.4'W	X	X	X	X	X	X	X
20.25	Tavolara	40	55.0'N	09	45.0'E					X		X
21.4	Annapolis	38	59.3'N	76	27.5'W	X	X	X	X	X	X	X
22.3	H.E. Holt	21	49.0'S	114	09.8'E					X		
24.0	Cutler	44	39.0'N	67	16.9'W	X	X	X	X	X	X	X
24.8	Jim Creek	48	12.3'N	121	54.9'W		X	X	X		X	
28.5	Aguada	18	24.0'N	67	10.7'W		X	X	X	X	X	X
51.6	Annapolis	38	59.7'N	76	27.9'W	X	X	X	X	X	X	X
55.5	Thurso	58	36.0'N	03	40.0'W	X	X	X	X	X	X	X
57.4	Grindavik	63	50.9'N	22	27.2'W	X	X	X	X	X	X	X
59.0	Nea Makri	38	09.0'N	24	02.0'E					X		X
77.15	Driver	36	48.0'N	76	30.0'W		X	X	X	X	X	X
88.0	Annapolis	38	59.6'N	76	27.7'W	X	X	X	X	X	X	X
134.9	Annapolis	38	59.6'N	76	27.7'W	X	X	X	X	X	X	X
142.25	Grindavik	63	50.9'N	22	27.2'W	X	X	X	X	X	X	X
148.5	Nia Makri	38	09.0'N	24	02.0'E					X		X

Table 1.1 VLF/LF Frequencies Recorded on the GTS Callaghan and C-141 MAC Aircraft Flights.

Freq (kHz)	Aircraft	Ship			
	6/84, 2/85 & 9/85	3/07/85 7/01/85	7/01/85 9/08/85	9/08/85 10/18/85	10/18/85 4/26/86
26.0	X	X	X	X	
63.0	X		X	X	X

Table 1.2 Noise channels monitored on the GTS Callaghan and C-141 aircraft.

1.2 Navigational Tracks

The trips made in the Atlantic by the GTS Callaghan can be placed into three groups: 1) trips originating on the east coast of the United States to Germany; 2) trips originating on the east coast of the United States into Mediterranean and then Germany; and 3) trips originating on the east coast of the United States into the Gulf of Mexico. Table 1.3 lists the origin/destination for cruises 1 to 30, and Table 1.4 lists the origin/destination for cruises 31 to 52. The listed date of each cruise is in the Julian format (i.e., the year number followed by the day number, YYDDD) Table 1.5 lists the approximate location of the harbors used by the Callaghan. Figure 1.2 depicts the navigational track used by the GTS Callaghan for cruises 1,2 and 3. Appendix A contains navigation plots for all the cruises taken by the Callaghan during the data collection period (3/29/85 to 4/26/86, or 85088 to 86116 Julian).

During June, 1984, and February and September, 1985 data collection flights were conducted in the North Atlantic Ocean area using MAC C-141 aircraft. The origin and destination of each flight for June, 1984, February, 1985, and September, 1985 are listed in Table 1.6, 1.7, and 1.8, respectively. During September, 1985, eight VLF/LF data collection flights were made across the Atlantic Ocean. Figure 1.3 illustrates the navigational paths taken during 3 consecutive September flights. Appendix A contains navigation plots of all C-141 data collection flights.

Cruise No.	Origin	Destination	Start Date	Stop Date
1	Bayonne	Bremerhaven	85088	85096
2	Bremerhaven	Charleston	85100	85109
3	Charleston	Bayonne	85110	85111
4	Bayonne	Bremerhaven	85114	85122
5	Bremerhaven	Bayonne	85125	85133
6	Bayonne	Bremerhaven	85135	85142
7	Bremerhaven	Bayonne	85143	85150
8	Bayonne	Bremerhaven	85151	85158
9	Bremerhaven	Bayonne	85159	85165
10	Bayonne	Bremerhaven	85168	85174
11	Bremerhaven	Bayonne	85176	85182
12	Bayonne	Charleston	85183	85184
13	Charleston	Savannah	85185	85185
14	Savannah	Alexandria	85189	85200
15	Alexandria	Bremerhaven	85202	85208
16	Bremerhaven	Bayonne	85210	85216
17	Bayonne	Bremerhaven	85220	85226
18	Bremerhaven	Alexandria	85228	85234
19	Alexandria	Savannah	85237	85249
20	Savannah	Bremerhaven	85253	85261
21	Bremerhaven	Norfolk	85263	85271
22	Norfolk	Charleston	85273	85273
23	Norfolk	Charleston	85296	85297
24	Charleston	Rotterdam	85298	85305
25	Rotterdam	Liverpool	85307	85308
26	Liverpool	Antwerp	85310	85311
27	Antwerp	Bremerhaven	85312	85313
28	Bremerhaven	Charleston	85316	85325
29	Charleston	Bayonne	85326	85327
30	Bayonne	Norfolk	85332	85332

Table 1.3 GTS Callaghan cruises 1 to 30.

Cruise No.	Origin	Destination	Start Date	Stop Date
31	Norfolk	Savannah	85335	85342
32	Savannah	Cristobal	85339	85342
33	Cristobal	Savannah	85344	85347
34	Savannah	Puerto Cortez	85351	85353
35	Puerto Cortez	Cristobal	85355	85356
36	Cristobal	Jacksonville	85357	85360
37	Jacksonville	Zeebrugge	85363	86006
38	Zeebrugge	Bremerhaven	86008	86008
39	Bremerhaven	Bayonne	86010	86019
40	Bayonne	Charleston	86035	86037
41	Charleston	Rotterdam	86039	86047
42	Rotterdam	Bremerhaven	86048	86049
43	Bremerhaven	Beaumont	86053	86063
44	Beaumont	Charleston	86066	86067
45	Charleston	Rotterdam	86068	86075
46	Rotterdam	Bogen	86077	86079
47	Bogen	Morehead City	86083	86092
48	Morehead City	Charleston	86095	86095
49	Charleston	Bayonne	86096	86097
50	Bayonne	Rotterdam	86098	86105
51	Rotterdam	Bremerhaven	86106	86106
52	Bremerhaven	Bayonne	86108	86115

Table 1.4 GTS Callaghan cruise 31 to 52.

Harbor	Longitude	Latitude
Alexandria	31° 10'N	29° 50'E
Bayonne	40° 41'N	74° 06'W
Bogen	68° 12'N	15° 28'E
Bremerhaven	53° 33'N	08° 35'E
Charleston	32° 47'N	79° 55'W
Cristobal	09° 32'N	79° 49'W
Jacksonville	30° 20'N	81° 39'W
Morehead City	34° 43'N	76° 43'W
Norfolk	36° 51'N	76° 17'W
Puerto Cortez	16° 02'N	87° 54'W
Savannah	32° 05'N	81° 05'W

Table 1.5 Approximate location of the major harbors visited by the Callaghan.

Trip No.	Origin	Takeoff Time	Destination	Landing Time
1	McGuire	6/06/84 2056Z	Keflavik	6/07/84 0240Z
2	Keflavik	6/09/84 2204Z	McGuire	6/10/84 0342Z
3	Norfolk	6/13/84 2335Z	Keflavik	6/14/84 0514Z
4	Keflavik	6/14/84 2305Z	McGuire	6/15/84 0459Z
5	McGuire	6/15/84 1914Z	Norfolk	6/15/84 1952Z
6	Norfolk	6/15/84 2323Z	Goose Bay	6/16/84 0246Z
7	Goose Bay	6/16/84 0417Z	Keflavik	6/16/84 0701Z
8	Keflavik	6/16/84 2314Z	McGuire	6/17/84 0446Z
9	Charleston	6/17/84 1300Z	McGuire	6/18/84 0025Z
10	McGuire	6/18/84 0507Z	Mildenhall	6/18/84 1219Z
11	Mildenhall	6/23/84 1404Z	Dover	6/23/84 2243Z
12	Dover	6/24/84 0245Z	Charleston	6/24/84 0406Z
13	Charleston	6/25/84 2249Z	Prestwick	6/26/84 0646Z
14	Prestwick	6/26/84 0830Z	Mildenhall	6/26/84 0924Z
15	Mildenhall	6/28/84 1015Z	Bremgarten	6/28/84 1126Z
16	Bremgarten	6/28/84 1444Z	Goose Bay	6/28/84 2115Z
17	Goose Bay	6/28/84 2333Z	Elgin	6/29/84 0428Z

Table 1.6 Origin, destination, takeoff, and landing time for June, 1984 C-141 flights.

Trip No.	Origin	Takeoff Time	Destination	Landing Time
1	McGuire	2/06/85 1911Z	Norva	2/06/85 2032Z
2	Norva	2/06/85 2339Z	Keflavik	2/07/85 0617Z
3	Keflavik	2/07/85 2159Z	McGuire	2/08/85 0356Z
4	McGuire	2/08/85 2019Z	Norva	2/08/85 2120Z
5	Norva	2/08/85 2344Z	Keflavik	2/09/85 0630Z
6	Keflavik	2/14/85 2227Z	McGuire	2/15/85 0439Z
7	McGuire	2/16/85 0353Z	Keflavik	2/16/85 0906Z
8	Keflavik	2/16/85 1143Z	Lages	2/16/85 1546Z
9	Lages	2/17/85 1121Z	Andrews	2/17/85 1808Z
10	Andrews	2/17/85 1903Z	McGuire	2/17/85 1939Z
11	McGuire	2/18/85 0941Z	St. Johns	2/18/85 1216Z
12	St. Johns	2/18/85 1420Z	Thule	2/18/85 1939Z
13	Thule	2/19/85 1245Z	Sondrestrom	2/19/85 1451Z
14	Sondrestrom	2/19/85 1548Z	Goosebay	2/19/85 1821Z
15	Goosebay	2/19/85 1957Z	McGuire	2/19/85 2309Z
16	Charleston	2/21/85 0004Z	Prestwick	2/21/85 0705Z
17	Prestwick	2/21/85 0935Z	Mildenhall	2/21/85 1045Z
18	Mildenhall	2/22/85 1435Z	Dover	2/22/85 2355Z
19	Dover	2/23/85 0207Z	Charleston	2/23/85 0302Z
20	Charleston	2/24/85 0528Z	Mildenhall	2/24/85 1340Z
21	Mildenhall	2/26/85 1528Z	Charleston	2/27/85 0136Z

Table 1.7 Origin, destination, takeoff, and landing time for February, 1985 C-141 flights.

Trip No.	Origin	Takeoff Time	Destination	Landing Time
1	McGuire	9/17/85 0148Z	Lages	9/17/85 0644Z
2	Lages	9/17/85 1118Z	Frankfurt	9/17/85 1526Z
3	Frankfurt	9/18/85 1054Z	Andrews	9/18/85 2015Z
4	Andrews	9/18/85 2240Z	McGuire	9/18/85 2308Z
5	Wright Patterson	9/21/85 0952Z	Lages	9/21/85 1526Z
6	Lages	9/21/85 1750Z	Frankfurt	9/21/85 2142Z
7	Frankfurt	9/25/85 1043Z	Andrews	9/25/85 1934Z
8	Andrews	9/25/85 2106Z	Wright Patterson	9/25/85 2136Z

Table 1.8 Origin, destination, takeoff, and landing time for September, 1985 C-141 flights.

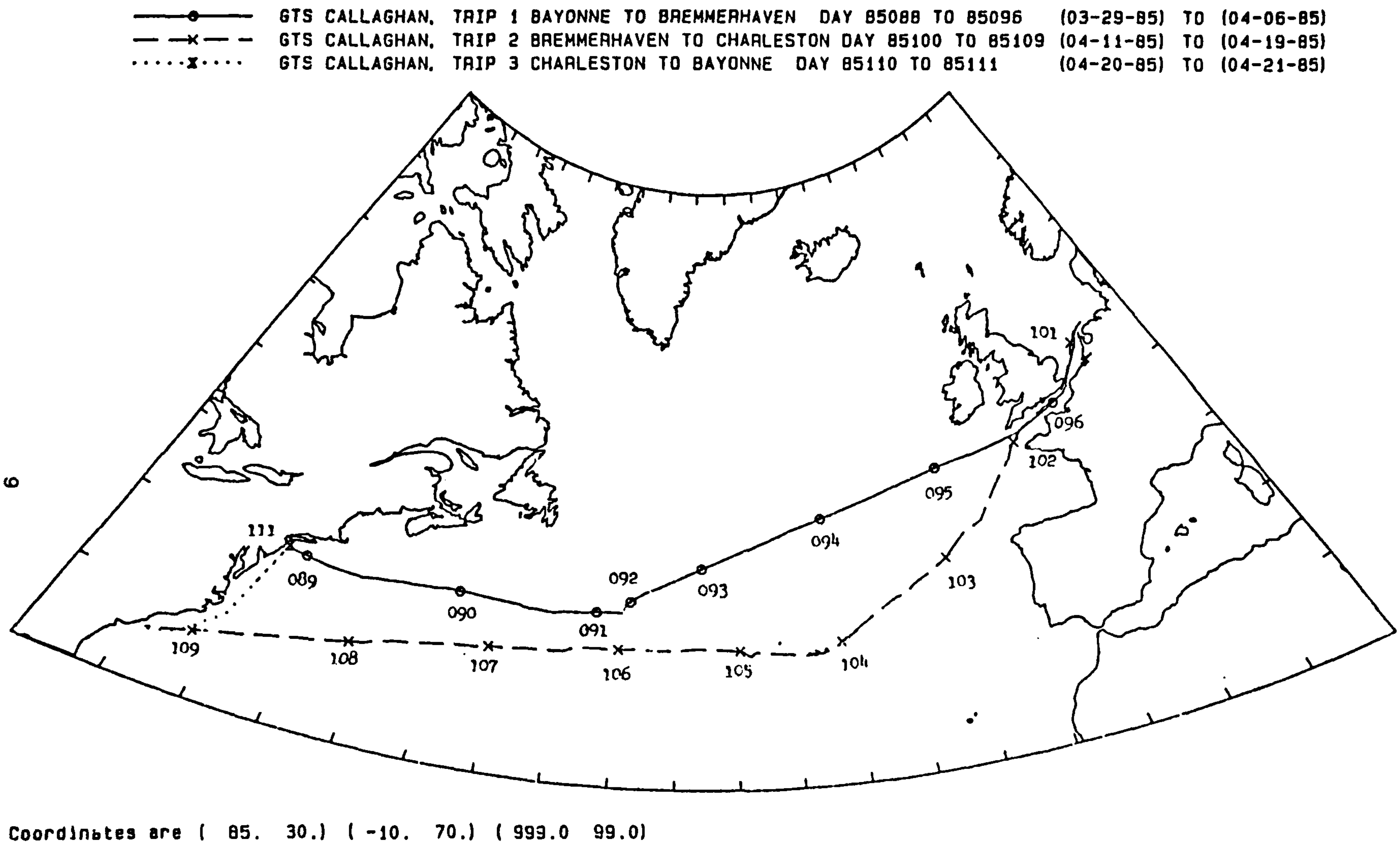


Figure 1.2 Example of navigational tracks of the GTS Callaghan during cruises 1-3. The marks on the tracks indicate the ships position at 0000Z on the Julian day number indicated.

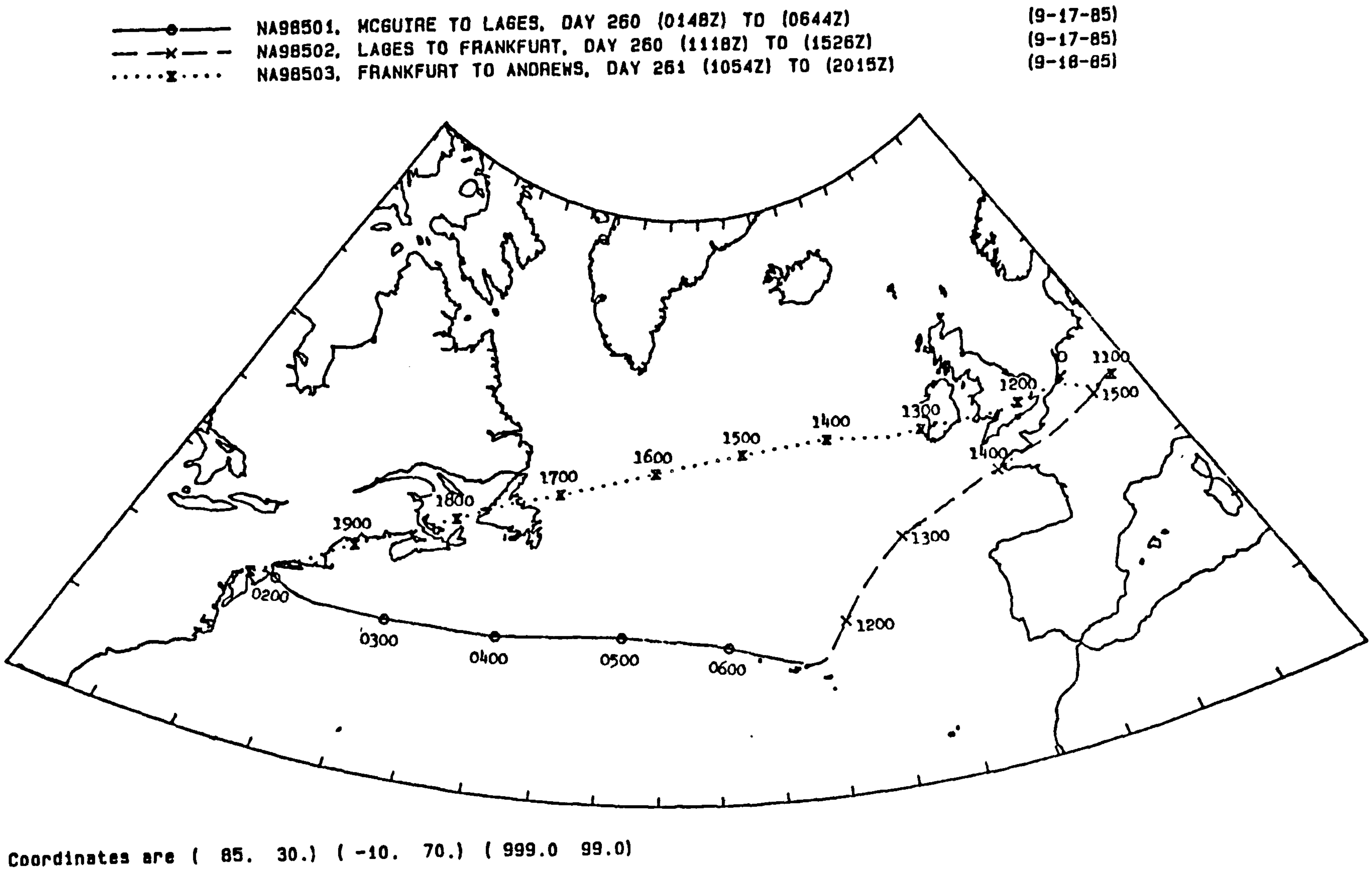


Figure 1.3 Example of navigational tracks used during 3 consecutive September, 1985 C-141 flights. The marks on the tracks indicate the aircrafts position at the GMT hour indicated.

SECTION 2 - RECORDING EQUIPMENT USED

The Hewlett Packard Model 3586C Selective Level Meter was used to record VLF/LF signal data discussed in this report for both the Callaghan cruises and C-141 flights. The computer, antenna and data recorder used were different between the ship and the aircraft. The Callaghan recording system uses an HP-87 computer while the MAC aircraft system uses an HP-85 computer. The following section discusses the recording equipment used during this project in greater detail. Figure 2.1 is a system diagram of the recording system used on the Callaghan. (The system is the same as that used during the TRANS-CONUS 86 project, [4], except that an HP-71B computer was used for system control.)

2.1 HP 3586C Selective Level Meter

The HP 3586C is a computer controllable signal analyzer, with a frequency range of 50 Hz to 32.5 MHz. It has three user selectable bandwidths of 20, 400, and 3100 Hz. The 400 Hz bandwidth was used to record signal level data. The 20 Hz bandwidth position was used to record spectrum data (normally a 2 kHz frequency "sweep" centered on selected frequencies), which is used to determine if a signal is on, as well as to determine the signal to noise ratio for a given frequency. The accuracy of the HP 3586C, for signal levels between +20 and -20 dBm is ± 0.45, for signal levels between -20 and -40 the accuracy is given as ± 0.70, and for signal levels between -40 and -80 dBm the accuracy is given as ± 2.2. These measures of instrument accuracies are taken from the manufacturer's performance specifications when the HP 3586C is used in the 100 dB range position and are described by HP engineers as maximum values[5]. Normally, accuracies are within 0.1 to 0.3 dB.

2.2 VHF Switch

An HP59307A VHF switch is used on the Callaghan to switch to a calibration signal (using the F_0 0 dBm output tracking signal from the HP 3586C) twice a day for one series of readings. The VHF switch is not used with the MAC C-141 recording system. Instead, the calibration signal is manually injected by the system operator during the flight.

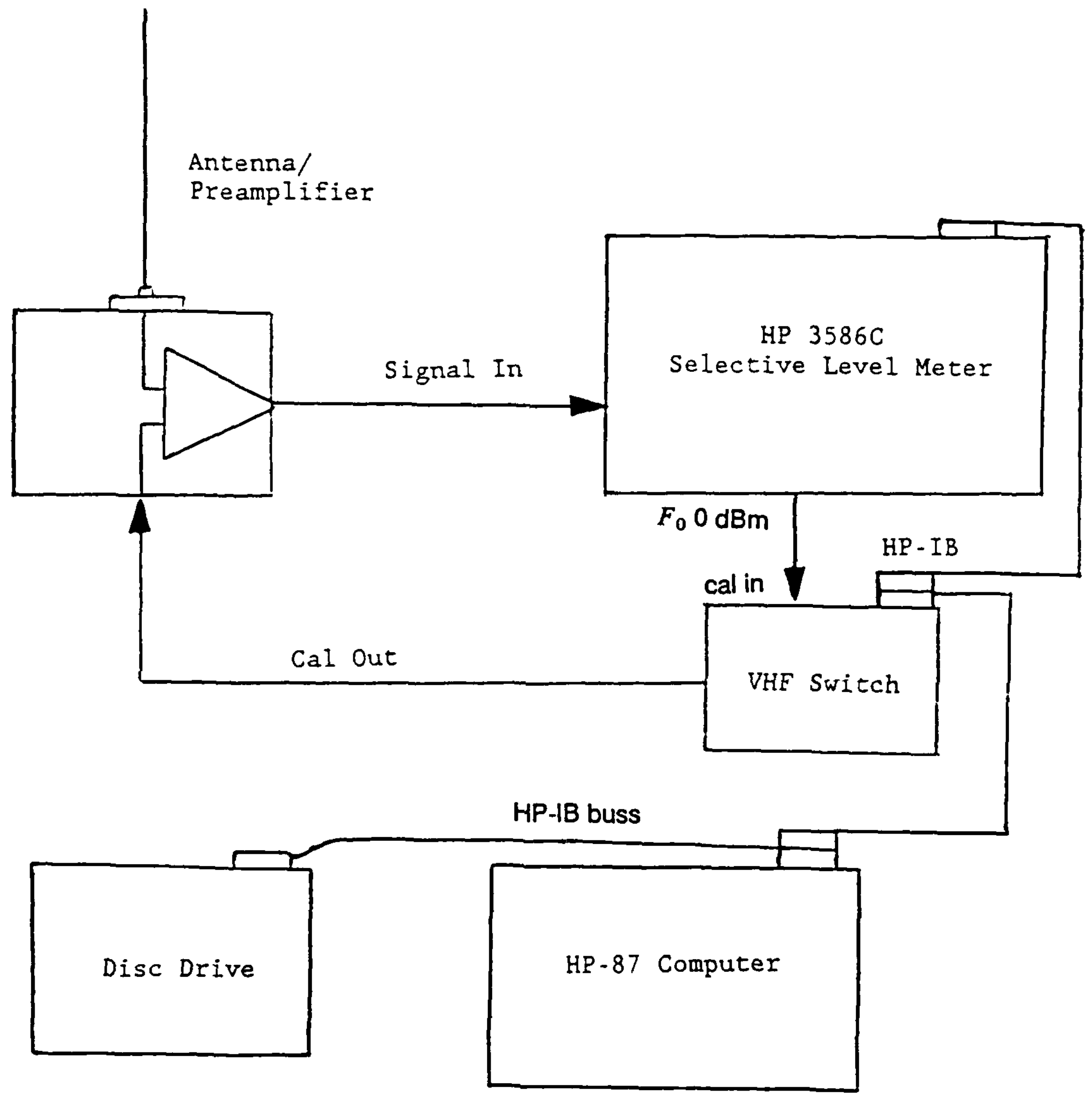


Figure 2.1 System diagram of the VLF/LF recording equipment used on the GTS Callaghan.

2.3 HP 85/87 Computers

The HP 85/87 computers are used to control signal data recorded during C-141 flights and Callaghan cruises, respectively. Both computers use HP-IB parallel interfaces to the HP 3586C, and both are programmed in the BASIC language.

The HP-85 computer has a self-contained unit that records data on tape cartridges. The amount of data that can be recorded on the tape cartridge varies with the number of frequencies recorded. Typically, with 15 frequencies monitored, a data tape will last about 10 hours. The HP-87 computer requires an external disc drive on which to store the recorded signal data.

2.4 HP 9121D Disc Drive

The HP 9121D disc drive, used on the Callaghan, contains two 3 1/2" disc drives which provide approximately 573 Kbytes of storage area for programs and data. This disk drive permits the storage of approximately 4 days of data on a disk (recording 16 frequencies every 6 minutes).

2.5 Preamplifier

The preamplifier, manufactured by NOSC, is transistor operated with a nominal gain of 20 or 40 dB. The gain position is selectable by re-soldering a jumper connector. High and low pass RC filter networks are connected to the high impedance FET input circuit to attenuate signals below 5 kHz and above 200 kHz. The preamplifier requires 7 milliamperes at 12 volts dc, ± 20% to function properly. Its circuit diagram is shown in Figure 2.2

The preamplifier on the GTS Callaghan is connected to an eight-foot fiberglass whip antenna. The antenna used aboard the C-141 aircraft is an 18" streamlined and tapered blade attached to an aircraft escape hatch. This antenna is easily transferred from one aircraft to another, requiring only a few seconds to install or remove by replacing an existing aircraft hatch on top of the fuselage with one to which the blade has been previously attached. This allows flexibility in selecting MAC routes on which prior permission had been obtained for data collection.

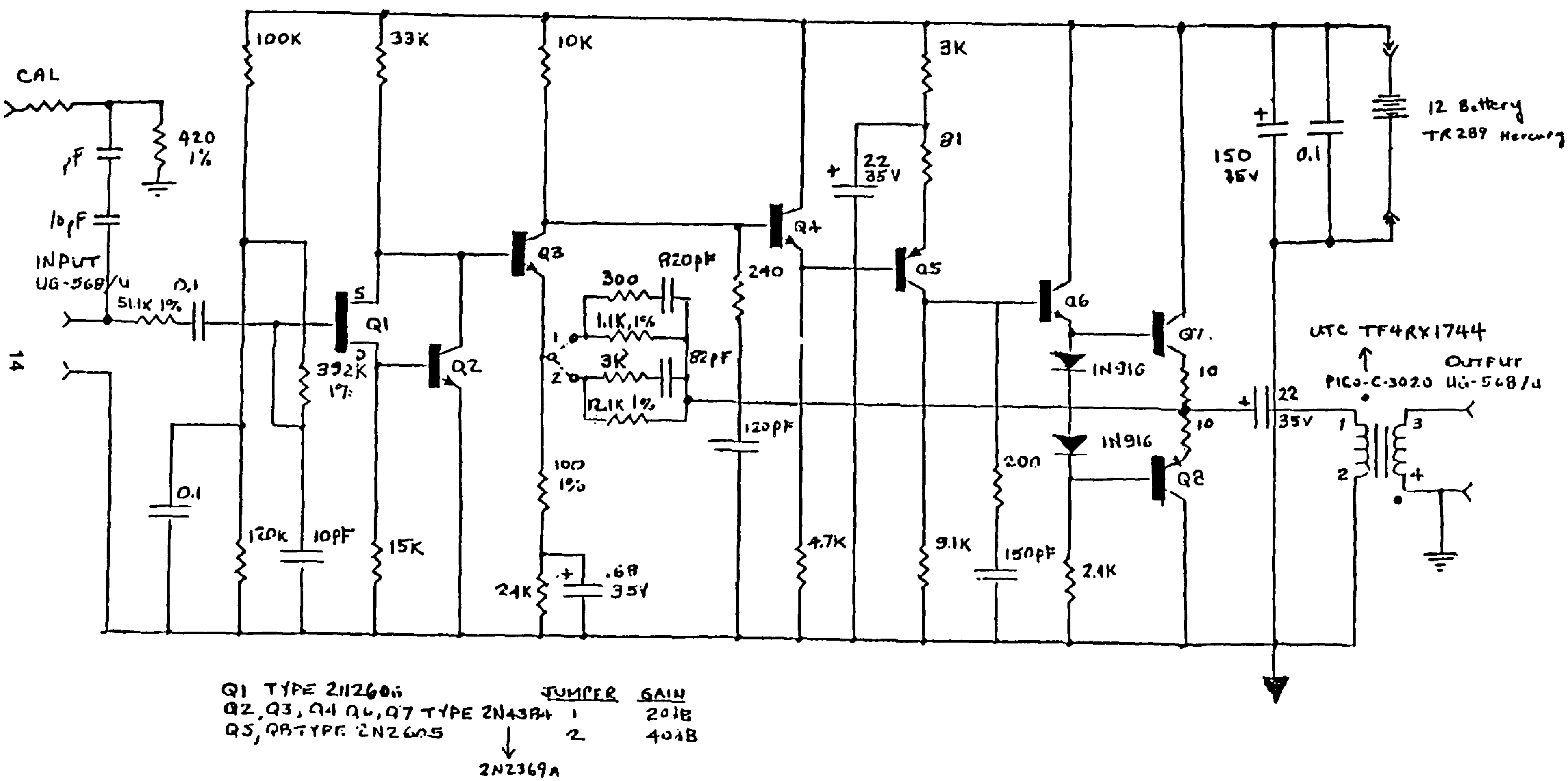


Figure 2.2 VLF/LF whip preamplifier circuit diagram.

SECTION 3 - RECORDED DATA TYPES

The VLF/LF measurement system is capable of monitoring up to 20 separate VLF/LF frequencies. The HP-3586C, under computer control, normally measures the 20 signal levels for each of these frequencies in sequence aboard the C-141 aircraft, completing each sequence approximately once every 70 seconds. This data is usually recorded using a 400 Hz bandwidth, but can be recorded using either a 20 or 400 Hz bandwidth.

On the Callaghan the 20 frequencies are recorded every 6 minutes. During the 4 to 5 minute periods between each 400 Hz bandwidth signal level measurement, the HP-3586C is programmed to record signal level spectra centered on each of the frequencies monitored using a 20 Hz bandwidth, starting 1 kHz below the center frequency and stepping, 25 Hz at a time, to 1 kHz above the center frequency. With one spectrum every 6 minutes, it takes up to 2 hours to complete spectral sweeps centered on the 20 monitored frequencies. This cycle of spectra is completed 4 times a day. Figure 3.1 illustrates signal and spectra data recorded on the Callaghan, on 10/01/85 (85274). Four spectra measurements were taken during this period, as well as the regular 400 Hz bandwidth data. The four dotted vertical lines indicate the time at which the spectra measurements were recorded.

The spectra data recorded at 0230, 0840, and 2030 (Figure 3.1) depicts the 20 Hz bandwidth signal to noise ratio when the transmitter is on. The spectrum at 1430 hours shows the noise at 20 Hz, as the transmitter was off the air from 1200 to 2000 hours. The noise level in this spectrum is approximately -52 dBV during recordings at 0230 and 0840, while the signal level is -16 dBV at the center frequency, 21.4 kHz. The Callaghan was in port at Bayonne, NJ during this time period. At midnight of each day, the time each of the four daily series of spectra begins is advanced one hour, so that after seven days they are occurring at approximately the same times as on the first day.

On C-141 aircraft flights spectra data is also recorded, however, the operator of the system must manually direct the HP-85 computer to begin taking a spectrum measurement on a user selectable frequency. Figure 3.2 illustrates spectra data recorded on flight 5, 9-21-85

(85264), centered at 88.0 kHz. The noise level in the spectra is approximately -90 dBV, while the signal level is -60 dBV at the center frequency of 88.0 kHz.

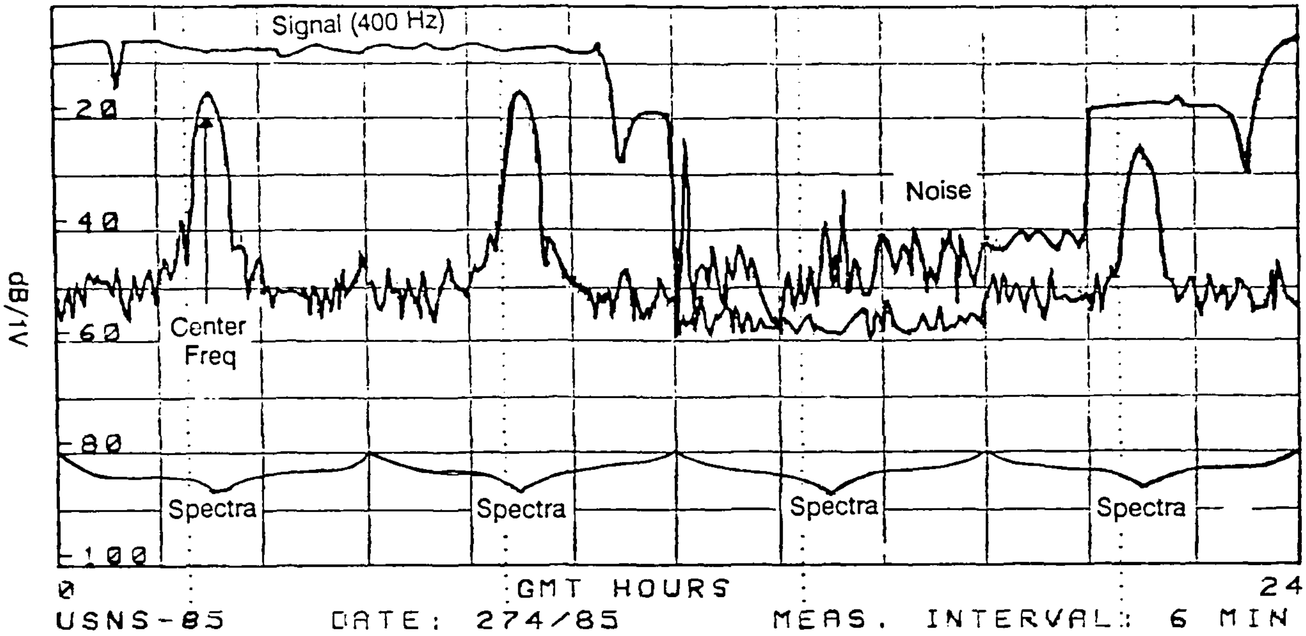


Figure 3.1 GTS Callaghan Signal/Spectrum Data at 21.4 kHz, Recorded 10/01/85.

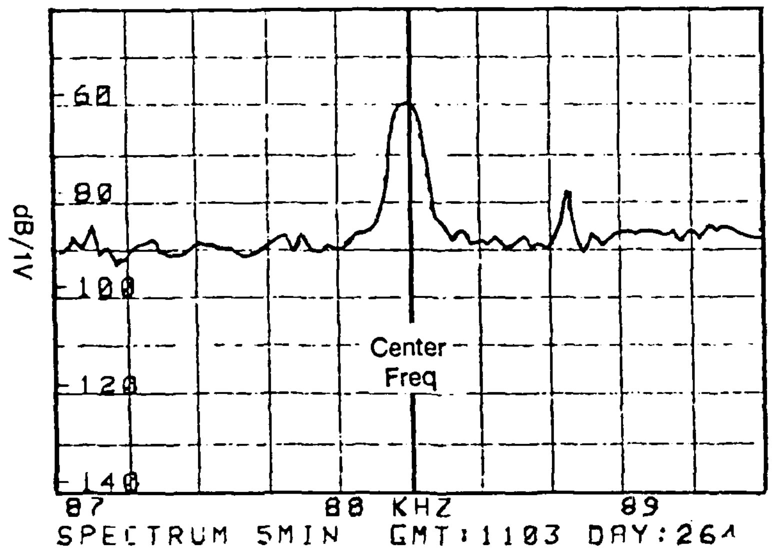


Figure 3.2 C-141 Spectrum at 88.0 kHz, recorded 9/21/85.

SECTION 4 - CALIBRATION PROCEDURES AND RESULTS

The VLF/LF signal data recorded on the GTS Callaghan and C-141 flights, in order to be of most use, must be calibrated to absolute field intensity (dB/μV/m). This requires taking a portable voltmeter and a calibrated loop antenna to several locations around the recording platform (aircraft or ship) and making field intensity readings, in Volts per meter (V/m), while a simultaneous recording of VLF/LF signal data (in dBV) is being recorded aboard the platform. These calibration measurements are used to determine a calibration factor, ΔdB(meters), where

$$\Delta dB = dB(\mu V) - dB(\mu V/m).$$

These calibration factors are used to convert the VLF data (recorded on the Callaghan or C-141 aircraft) to absolute field intensity.

4.1 Field Calibration Equipment

Figure 4.1 is a system diagram for the Sierra 127C calibration system used to calibrate the VLF/LF signal data discussed in this report. The equipment used to calibrate the VLF data consisted of a Sierra 127C Frequency Selective Voltmeter and an NOSC manufactured briefcase loop antenna system.

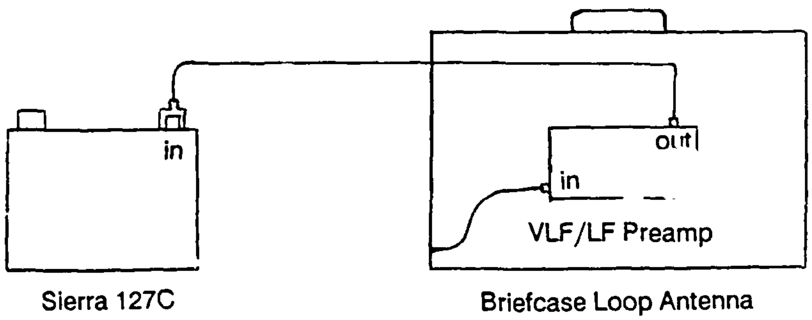


Figure 4.1 Sierra 127C VLF/LF calibration system diagram.

4.1.1 Sierra 127C Frequency Selective Voltmeter

The Sierra 127C is a battery powered, portable selective level voltmeter with a frequency range of 2 to 350 kHz. The amplitude accuracy of the Sierra 127C, when it has been properly calibrated, is +/- 1.0 dB. However, the actual error may be higher as the accuracy is also limited by the meter resolution, ability of the user to accurately "estimate" an average reading on the analog meter as it rapidly varies due to the signal modulation, and the stability of the instrument. Table 4.1 lists the specifications of the instrument[8].

Frequency Range	2 to 350 kHz
Input Level	-70 to +22 dBm
Amplitude Accuracy	+/- 1 dB
Frequency Accuracy	+/- 1 kHz
Bandwidth	250 Hz
Power	6 "D" Cells
Weight	15 pounds
Dimensions	12 x 7.5 x 7.5 inches

Table 4.1 Sierra 127C Specifications.

4.1.2 Briefcase Loop Antenna

The briefcase loop antenna system consists of the loop antenna and the VLF/LF preamplifier mounted inside a standard, leather covered, briefcase of composition construction. The 45 turn loop consists of 3 layers of 15 conductor ribbon cable, with the ends connected to provide one continuous conductor, covered with aluminum foil for shielding, and taped to the inside of the briefcase. Its rectangular shape is 16.5" x 11" in size. Details of the loop preamplifier are illustrated in Figure 4.1.1. The report "TRANS-CONUS 86 VLF/LF DATA ACQUISITION PROJECT" (TRCN86)[4] describes the use of a briefcase loop antenna system and [7] describes its necessary calibration. Figure 4.2 illustrates the correction factor curve for briefcase loop 1, which is used in calibrating the VLF data discussed in this report.

4.2 Calibration Sites

When selecting a calibration site, considerable care must be taken. Power lines, irregular ground contours, magnetic material, and local ground conductivity and its spatial variation can

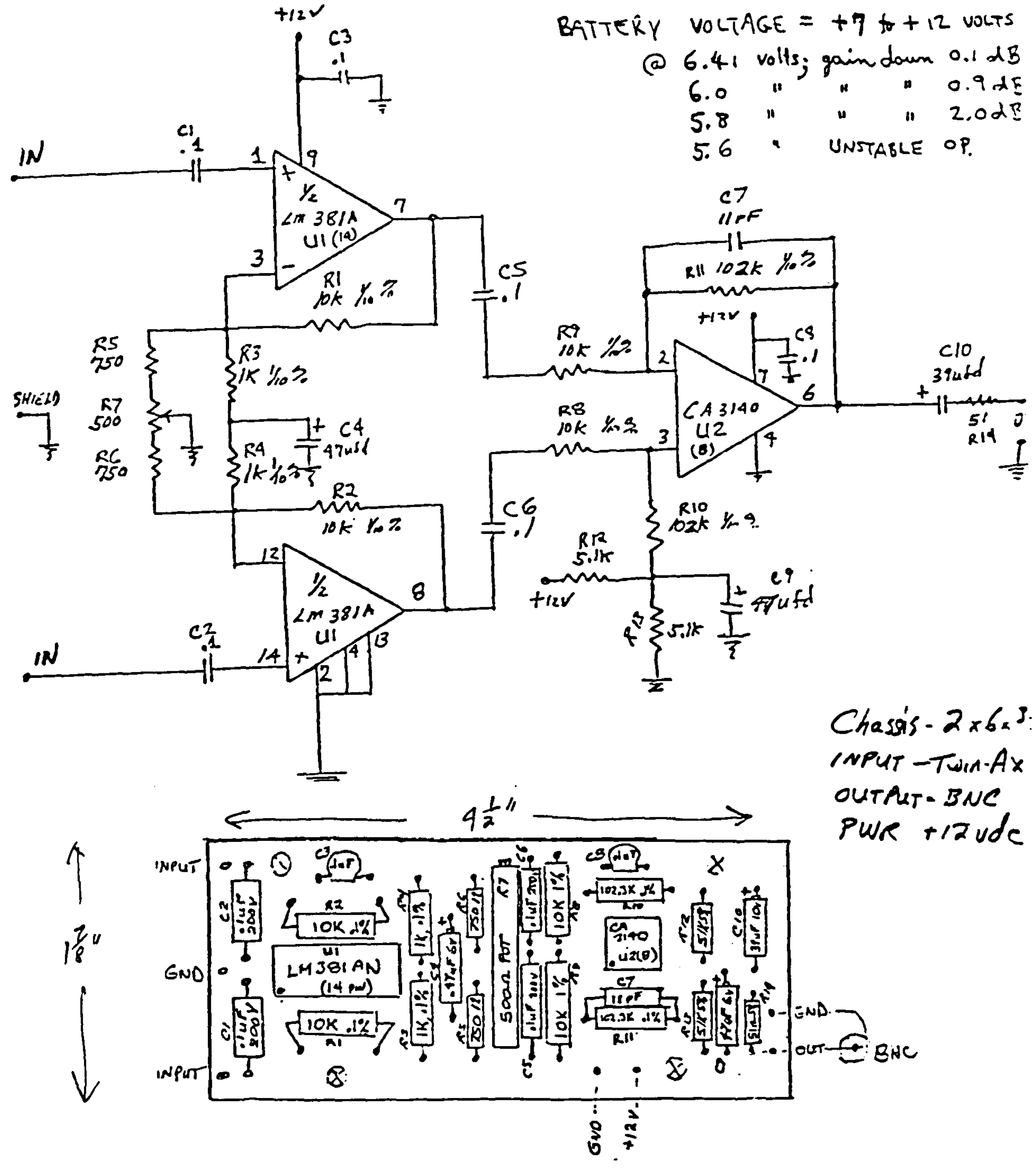


Figure 4.1.1 Circuit diagram and component layout of the VLF/LF Calibration preamplifier.

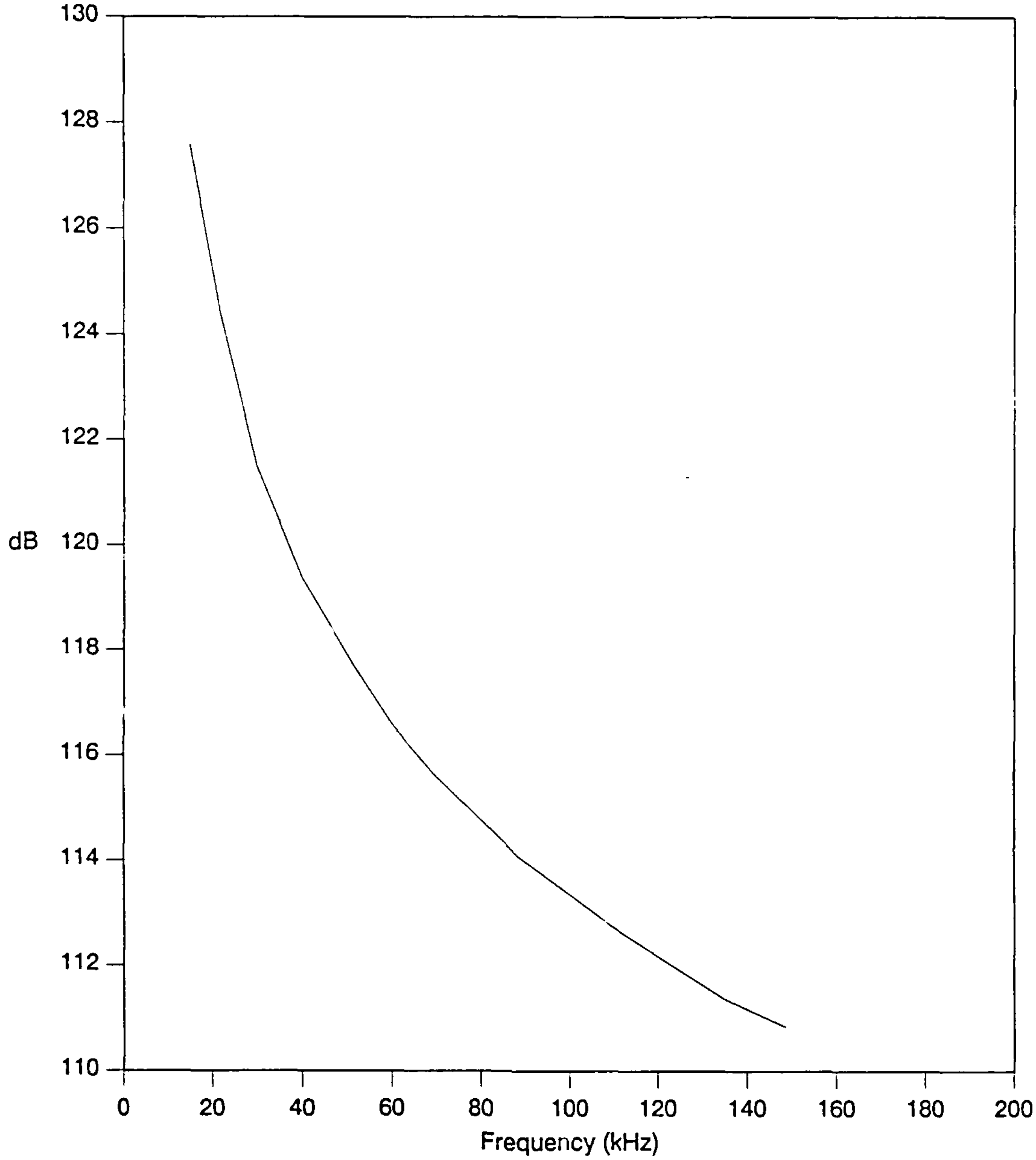


Figure 4.2 Briefcase Loop 1 Calibrated Correction Factor Curve.

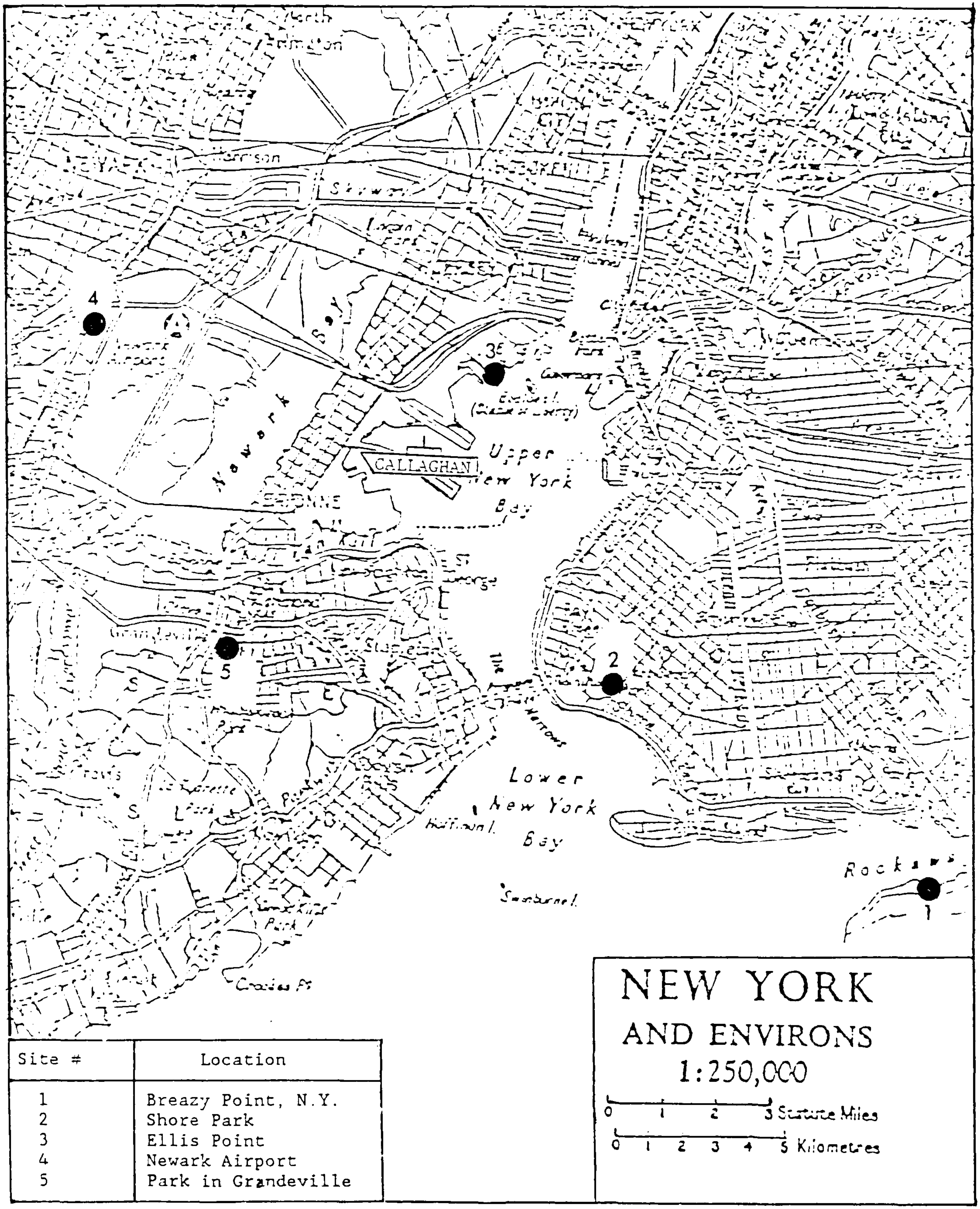
all influence the electromagnetic field, resulting in erroneous calibration results. While much in this area of radio science is still unknown, the ideal location in which to take field intensity measurements appears to be in the middle of a large open field (or body of water), with no overhead power lines, large obstructions, or large conducting or magnetic material in the immediate vicinity. Calibration measurements should be made at several sites (4 or more depending on the variability of the measurements) within an area of one or more wavelengths of the recording site (depending on frequency). This should average out the effects of any unknown perturbations of objects on the calibration.

4.2.1 GTS Callaghan Calibration

Several calibrations of the GTS Callaghan were made at various times of the year. Calibrations were performed while the ship was in port at Bayonne, New Jersey, and Charleston, South Carolina. Table 4.2 lists the dates during which these field calibrations were performed, the cruises for which the calibration is valid, as well as the location and reason for making the calibration. Figures 4.3 and 4.4 show the approximate locations used during calibrations of the Callaghan at Bayonne, N.J., and Charleston, S.C., respectively.

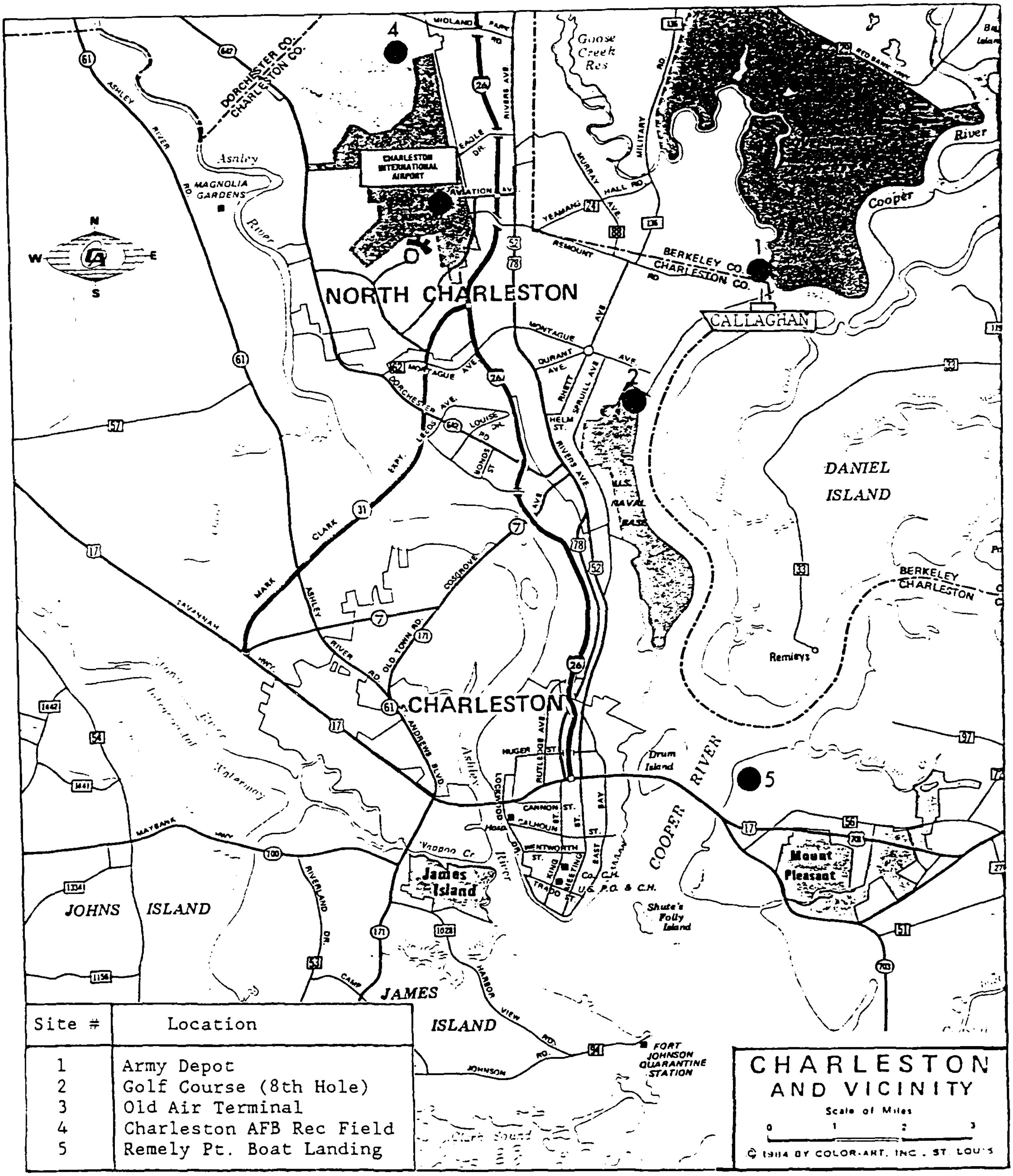
4.2.2 C-141 Aircraft Calibration

C-141 calibrations were performed at the sites listed in Table 4.3. During calibrations the C-141 aircraft was parked in the apron area. Signal data (in dBV) was recorded on 20 frequencies, in sequence, by the HP3586C system using two different antennas: (1) a four foot telescoping whip antenna (and preamp) located 50 to 75 feet in front of the aircraft; and (2) the hatch blade antenna. During these HP3586C recordings, field strength measurements were made at about the same time, approximately 50 to 100 feet away from the aircraft using the Sierra loop calibration system in order to determine the effective height, i.e., the calibration factor, of the whip and blade antennas. Relative voltage measurements were made using both a telescoping whip antenna and its preamplifier, and the blade antenna because at the time of these tests it was not known if the aircraft's blade antenna was omni-directional. After evaluating the calibration and VLF/LF signal data recorded on the aircraft, it appears that the direction of



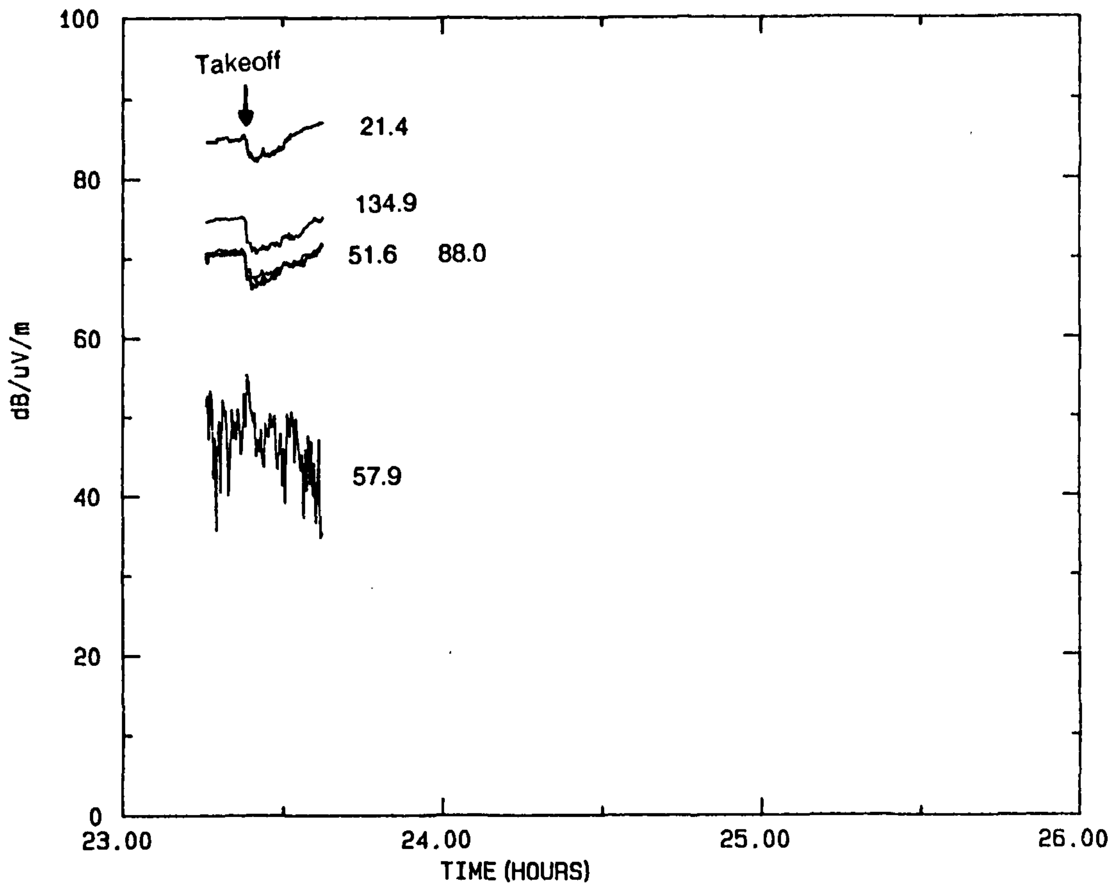
Site #	Location
1	Breazy Point, N.Y.
2	Shore Park
3	Ellis Point
4	Newark Airport
5	Park in Grandeville

Figure 4.3 Calibration locations visited in Bayonne, N J to calibrate the GTS Callaghan.



Site #	Location
1	Army Depot
2	Golf Course (8th Hole)
3	Old Air Terminal
4	Charleston AFB Rec Field
5	Remely Pt. Boat Landing

Figure 4.4 Calibration locations visited in Charleston, S C to calibrate the GTS Callaghan.



BEGIN : 06/15/84 AT 2315Z END : 06/15/84 AT 2338Z
STATION FREQ = 21.40 DELTA = 105.3
STATION FREQ = 51.60 DELTA = 103.7
STATION FREQ = 57.90 DELTA = 103.2
STATION FREQ = 88.00 DELTA = 100.5
STATION FREQ = 134.90 DELTA = 109.8

Figure 4.5 Effect of Attitude on C-141 VLF/LF signal data.

arrival of VLF/LF signals does not affect the signal voltage received on the blade antenna. As such, the relative voltage measurements made with the NOSC VLF/LF preamplifier/aircraft blade antenna combination were used to determine the field intensity measured by the aircraft data recording system, both on the ground and while airborne.

Data recorded on the C-141 aircraft was found to vary with the fuselage inclination variations, such as occur during takeoffs or landings, and when the aircraft is in a steep bank. During these periods the signal level recorded on the aircraft briefly varies up to 3 dBV. Figure 4.5 illustrates this during a takeoff from Norfolk. Table 4.4 lists the average observed relative voltage effects of takeoff and landings, as well as steep banking.

Date	Location	Preamp	Valid Cruises	Reason for Cal
3/8/85	Bayonne, N.J.	2	1 - 9	Initial Installation
8/4/85	Bayonne, N.J.	2	10-16	1/2 Antenna
8/6/85	Bayonne, N.J.	1	17-23	New Preamp
10/24/85	Charleston, S.C.	8	24-52	New Preamp

Table 4.2 Date, location, and preamp serial number used for calibrations, the primary reason for the calibration, and the cruise numbers for which the calibration applies.

Date	Location
6/09/84	Keflavik
6/13/84	Norfolk
6/14/84	Keflavik
6/15/84	McGuire
6/24/84	Dover
9/21/85	McGuire
9/21/85	Lages

Table 4.3 Date and location of C-141 calibrations.

Frequency (kHz)	Takeoff	Landing	Descending Right Bank	Descending Left Bank	Ascending Right Bank	Ascending Left Bank
19.0	-1.8	+1.4	-2.1	+0.0	-2.2	+1.7
21.4	-2.2	+1.1	-2.4	+0.0	-2.0	+1.5
51.6	-1.8	+1.4	-2.4	+0.0	-2.2	+1.1
55.5	-2.2	+1.3	-1.9	+0.0	-2.6	+2.4
134.9	-1.8	+1.0	-2.4	+0.0	-3.4	+1.0
Average Diff	-1.9	+1.2	-2.2	+0.0	-2.5	+1.5

Table 4.4 Average effect of takeoffs and landings on VLF/LF relative voltage levels as measured on C-141 aircraft during June, 1984. Data is negative when the voltage level decreased during the maneuver and is positive when the voltage level increases during the maneuver.

4.3 Calibration Results

The Sierra 127C calibration recording system measures absolute field intensity in volts per meter (V/m) while the aircraft or ship system is recording the relative signal level in volts (V). The ratio

$$V/(V/m) = m\ (meters),$$

or

$$20 \log V - 20 \log (V/m) = 20 \log m,$$

is used to convert the recorded voltage to absolute field intensity. "m" is a function of the effective height of the recording whip antenna, the antenna preamplifier gain, and the pertu.bation of the field at the recording and calibration sites[2].

In order to reduce the effects of local perturbations at any one calibration site, calibration measurements for the GTS Callaghan are made at several remote sites within 1 or more wavelengths of the ship while it was tied up at a dock.

The ship calibrations obtained in this way at Charleston as well as Bayonne allows an opportunity to evaluate and compare results for two different recording systems environments, i.e., ports and docks. Due to scheduling difficulties encountered on C-141 flights, it was not possible to perform calibrations at locations remote from the aircraft at the various airports. Instead, calibration measurements for the C-141 data were made in the apron area within 100 feet of the aircraft at a number of airports listed in Table 4.3. Figure 4.10 illustrates the calibration curve that is used to normalize the VLF/LF signal data recorded during C-141 flights. This calibration consists of calibration measurements taken during C-141 flights in June, 1984 and September, 1985. These data illustrate the repeatability of the calibration results using the above procedures.

An example of a plot of $20 \log m$ values for the GTS Callaghan is shown in Figure 4.6. The frequency response curve for the preamplifier used on the Callaghan during this calibration is also shown in Figure 4.6. Its position on the y-axis is adjusted to provide an estimated best fit

through the values of $20 \log m$ determined from the calibration measurements. This adjusted frequency response curve of the preamp is then the calibration factor used to determine the effective field intensity for all signal data recorded.

This procedure provides a calibration factor variation with frequency that represents an average of all frequencies calibrated at all calibration sites. The frequency response curve was measured in the laboratory by providing a calibration signal to the input of the preamplifier through a 20 pF capacitor to simulate the source impedance of the 8' whip antenna used on the GTS Callaghan. Figures 4.7 to 4.9 illustrate the remaining Callaghan calibration curves obtained using this procedure.

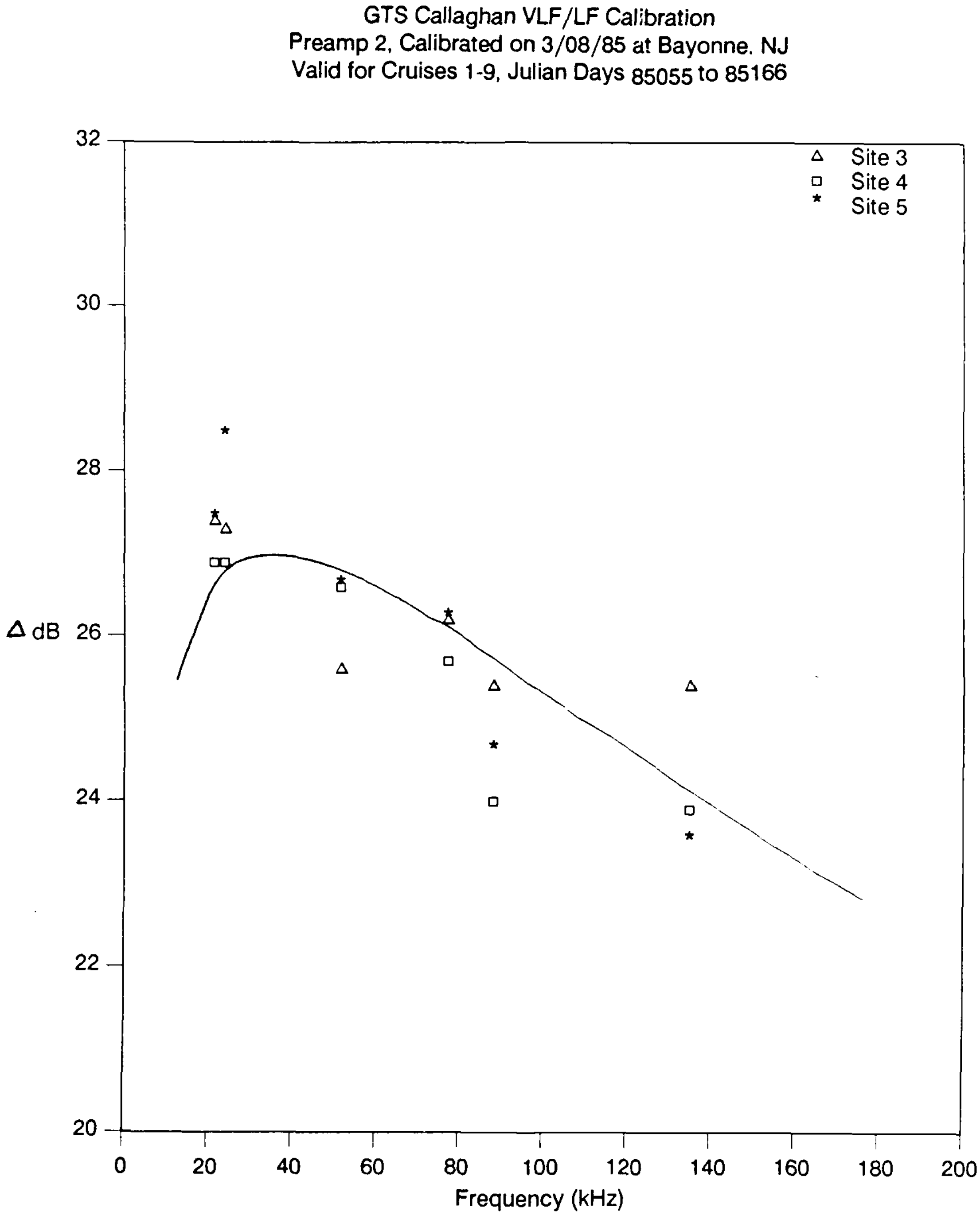


Figure 4.6 Calibration factor curve for preamp 2 with a 6 foot whip antenna. This curve applies to data recorded during cruises 1 to 9.

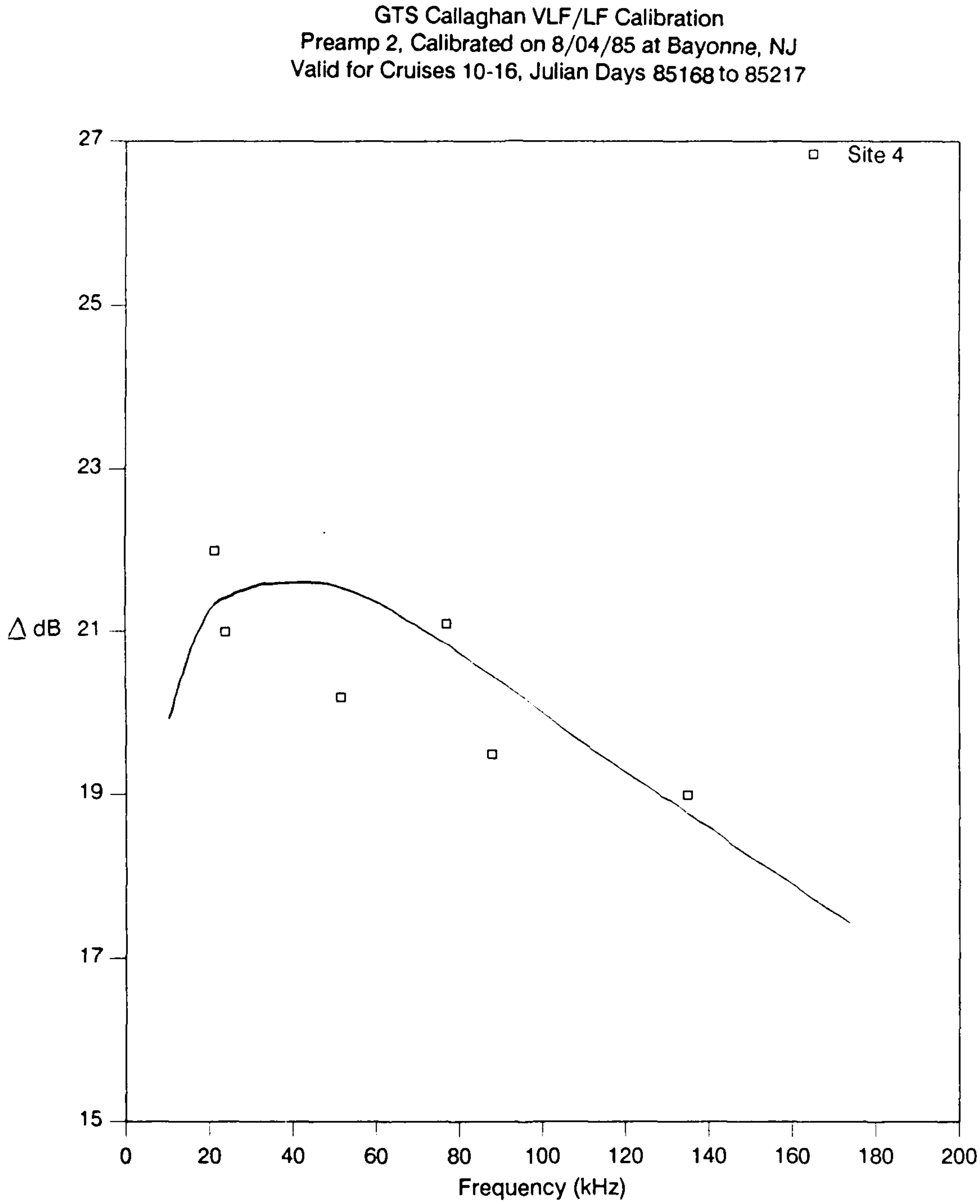


Figure 4.7 Calibration factor curve for preamp 2 after about 1/2 of the original 6 foot antenna broke off. This curve applies to data recorded during cruises 10 to 16.

GTS Callaghan VLF/LF Calibration
Preamp 1, Calibrated on 8/06/85 at Bayonne, NJ
Valid for Cruises 17-23, Julian Days 85219 to 85298

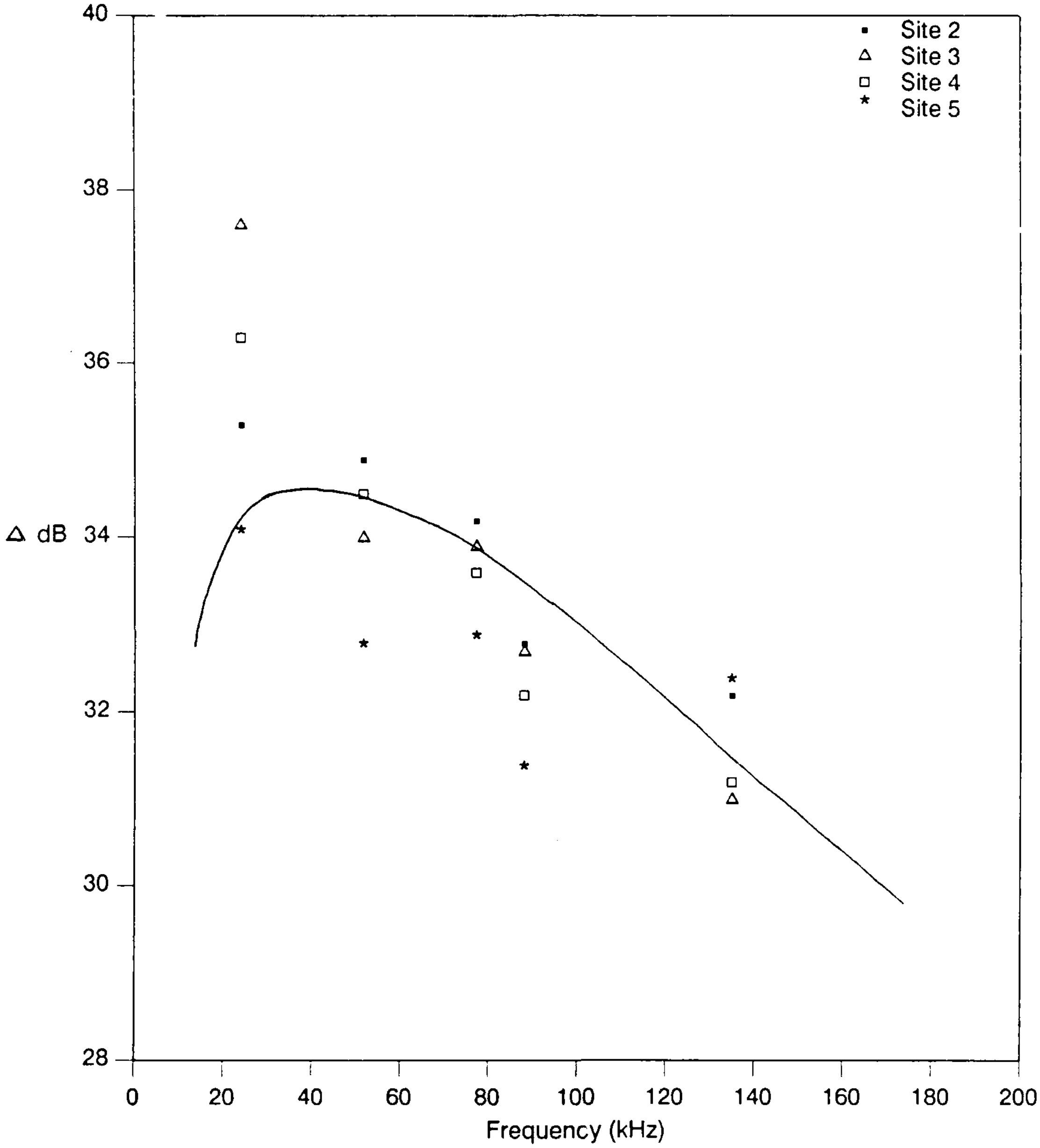


Figure 4.8 Calibration factor curve for preamp 1 and its 8 foot whip antenna. This curve applies to data recorded during cruises 17 to 23.

GTS Callaghan VLF/LF Calibration
Preamp 8, Calibrated on 10/24/85 at Charleston, SC
Valid for Cruises 24-52, Julian Days 85298 to 86157

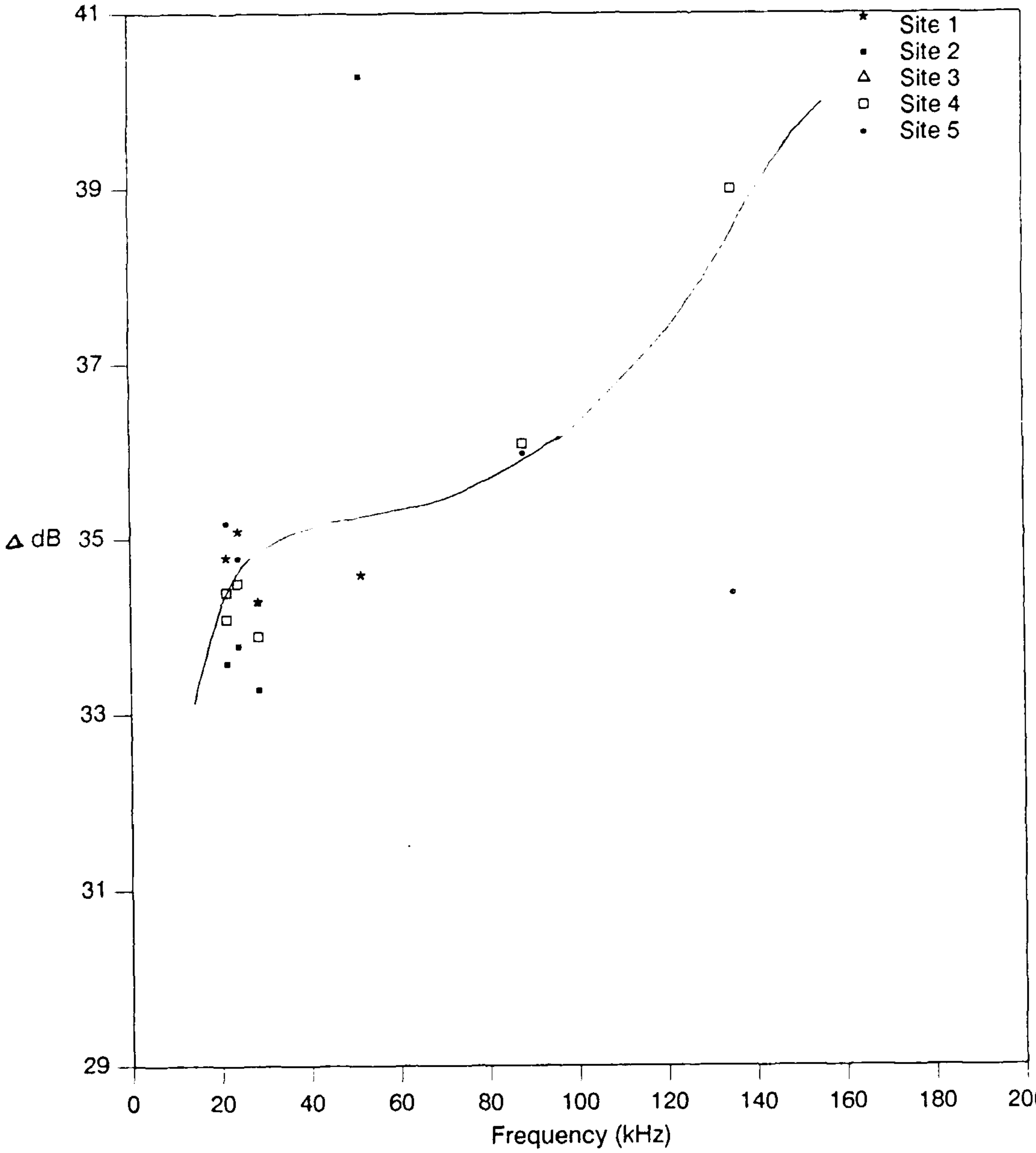


Figure 4.9 Calibration factor curve for preamp 8 and its 8 foot whip antenna. This curve applies to data recorded during cruises 24 to 52.

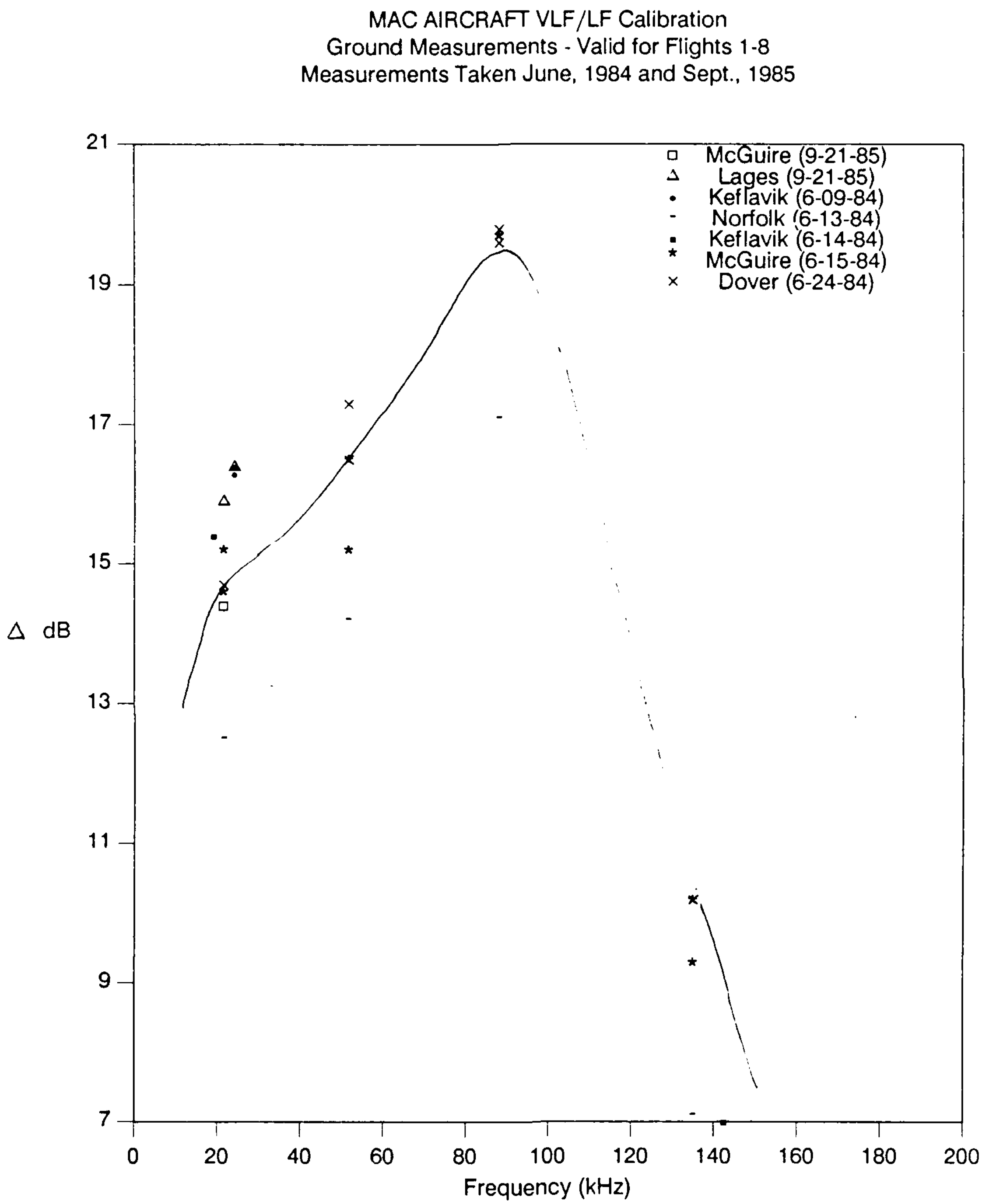


Figure 4.10 Calibration factor curve for C-141 flights where the hatch blade antenna and preamplifier serial #3 were used.

SECTION 5 - NORMALIZED VLF/LF DATA

When the calibration of the C-141 aircraft and the GTS Callaghan data has been determined (Section 4), the signal data collected can be normalized to absolute field intensity (dB/μV/m). Figure 5.1 illustrates signal data, normalized to absolute field intensity, collected on the GTS Callaghan during a cruise from Bayonne, NJ to Bremerhaven, Germany. The data measured is from the Annapolis, MD transmitter broadcasting at 21.4 kHz. This figure illustrates the recorded diurnal variation, as well as variation in signal strength as a function of distance from the transmitter. The "+" marks at the top of the figure indicate the distance of the ship from the transmitter at 0000Z on the Julian day number indicated. Every 12 hours a "calibration" signal is injected into the preamplifier to measure the stability of the system, these "calibration" measurements are labeled on Figure 5.1 with a "C". The correction factor, "DELTA dB", listed in the lower left corner of Figure 5.1, used to normalize the recorded signal data, is

$$\text{DELTA dB} = (120 - 20 \log \overline{m}) = 93.30.$$

This is the factor used to convert the recorded dBV data to field intensity, i.e.,

$$dB\,(\mu V/m) = dBV + \text{DELTA dB}.$$

Figure 5.1 also illustrates the signal to noise ratio of the data at this frequency. On Julian day 85092 (4/02/85) the transmitter went off the air for approximately 8 hours. During this time the recorded noise level is approximately 30 dB/μV/m for the 400 Hz bandwidth of the HP3586C, while the signal levels which bracket this off period are approximately 64 dB/μV/m. Thus, the signal to noise ratio at 3000 km is 34 dB/μV/m. The signal to noise ratio is even better closer to the transmitter (up to 50 dB signal to noise ratio, assuming that the noise level did not vary). Even as far away as 6000 km, the signal to noise ratio is at least 15 dB during the day (again assuming that the noise level did not vary). Appendix H contains all normalized Callaghan data (trips 1 to 52) plotted as a function of distance from the monitored transmitter.

Figure 5.2 illustrates C-141 aircraft data normalized to dB/μV/m for the 21.4 kHz transmitter at Annapolis, MD, recorded on September 18, 1985 (flight 3, of the September, 1985 series of data flights). This plot aiso illustrates the calibration signal which is manually injected

by the operator several times during a flight. These calibration measurements are used to verify that the system's gain has remained stable over the course of a flight and a series of flights. Appendix G contains all normalized C-141 aircraft data plotted as a function of distance from the monitored transmitter.

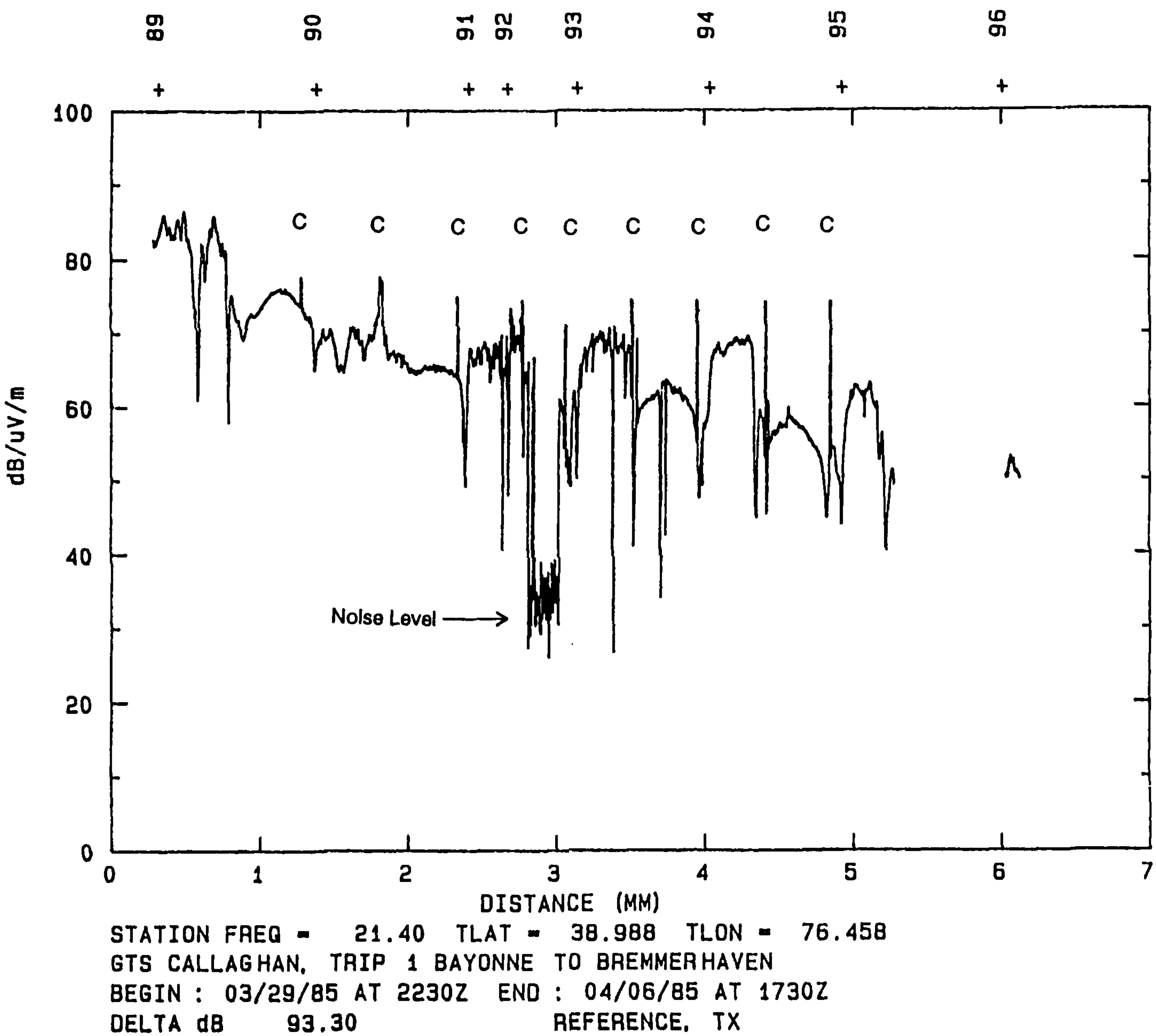
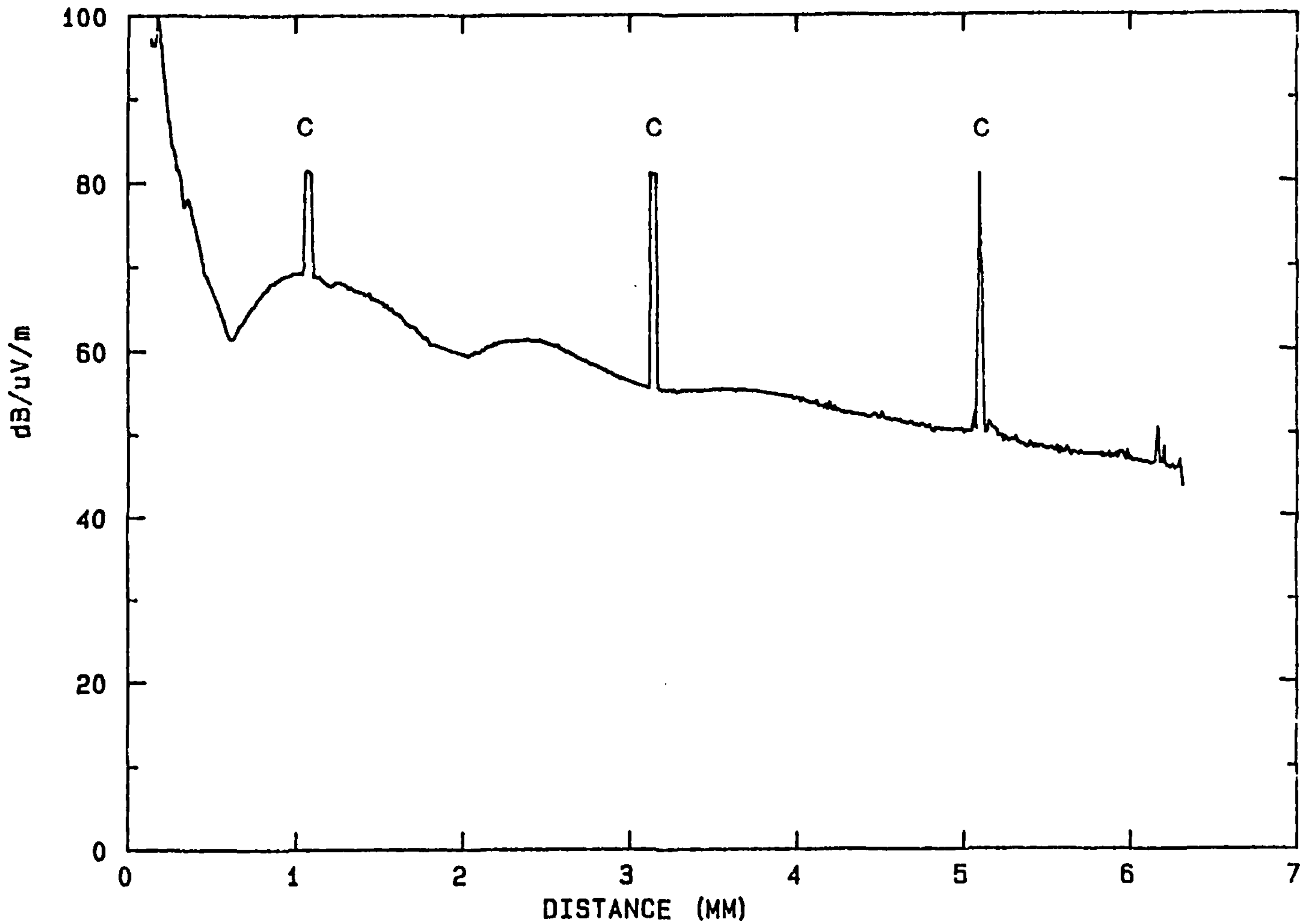


Figure 5.1 VLF/LF data at 21.4 kHz (Annapolis, MD) as measured from the GTS Callaghan.



STATION FREQ = 21.40 TLAT = 38.988 TLON = 76.458
NA98503, FRANKFURT TO ANDREWS, DAY 261 (1054Z) TO (2015Z)
BEGIN : 09/18/85 AT 1054Z END : 09/18/85 AT 2015Z
DELTA dB 101.40

Figure 5.2 VLF/LF data at 21.4 kHz (Annapolis, MD) as measured during C-141 flight 3.

SECTION 6 - RADIATED POWER MEASUREMENTS

It is possible to determine the radiated power from a VLF/LF transmitter by measuring the signal strength as a function of distance from the transmitter. This is most accurate when recording data at a distance of between 10 to 100 km of the transmitter. The resulting signal strength data (in dB/μV/m) is then plotted as a function of logarithmic distance from the transmitter and an estimated "best fit" straight line, with a slope of 20 dB per decade, is drawn through the data.

The theoretical field strength produced by a "short" vertical antenna radiating 1 kw of power in a lossless environment is 69.5 dB/μV/m at a range of 100 km and varies inversely with distance (20 dB per decade)[9]. To determine the radiated dB(kw), note the "Y" intercept at the 100 km range of the "best fit" line through the signal data and its dB difference from 69.5. Specifically,

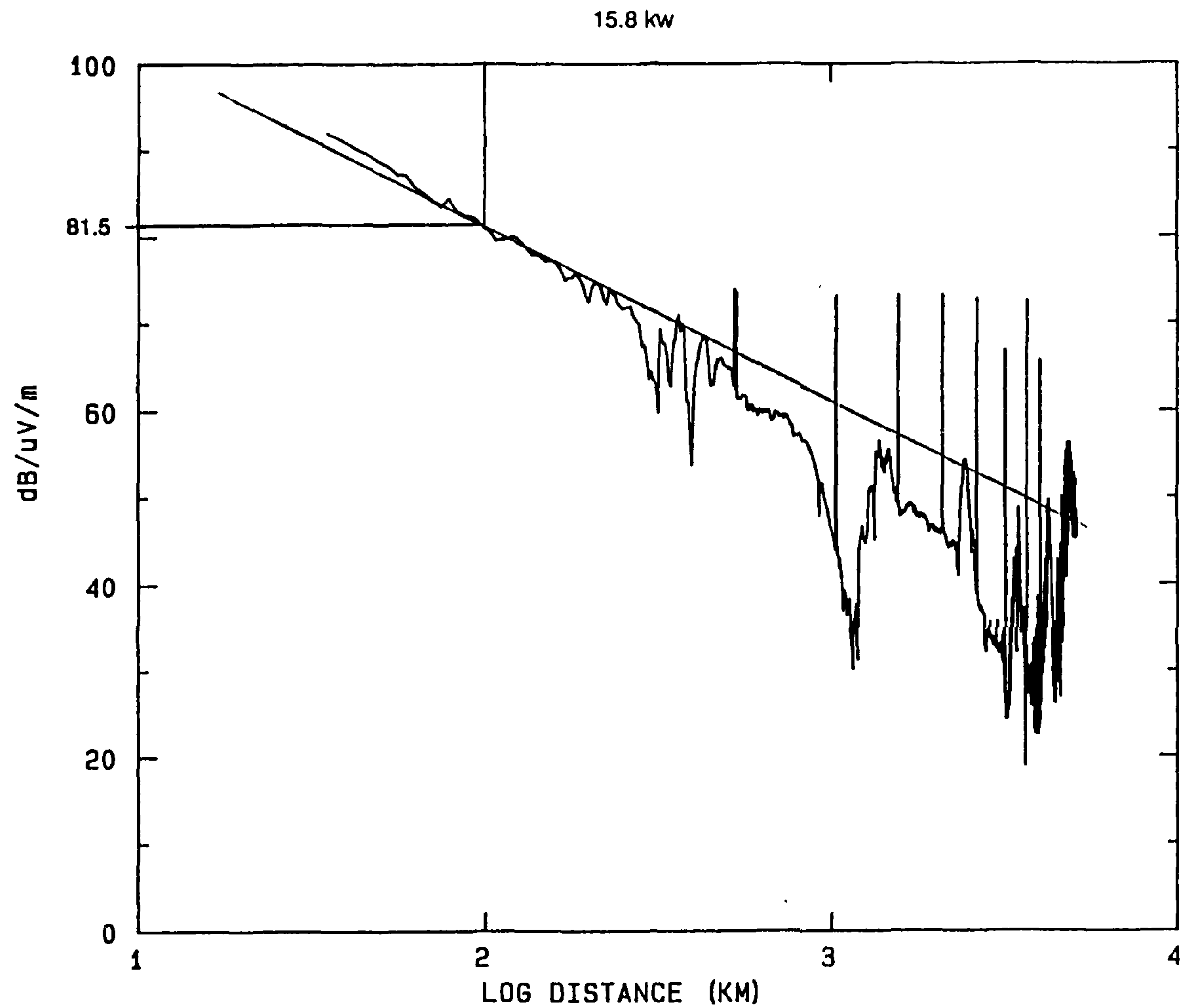
$$dB(kw) = [intercept(dB)] - 69.5.$$

This analysis has been made for most of the data recorded close to a transmitter. The log distance plots used to calculate the radiated power measurements, for the Callaghan and C-141 flights discussed in 6.1 and 6.2, respectively, are found in Appendix C.

6.1 Radiated Power Calculations from Callaghan Data

The GTS Callaghan, while cruising to and from Germany, made several close approaches (within 50 km) to the transmitter at Thurso, Scotland operating at 55.5 kHz. Figure 6.1 illustrates the log distance plot obtained for cruise 8 as the ship approaches the transmitter. The radiated power for the 55.5 kHz Thurso transmitter, as computed from the Callaghan data, are listed in Table 6.1.

During June, 1984, field strength measurements were made on the ground at a distance of between 9 and 34 km from the Thurso, Scotland transmitter to determine the radiated power[1]. Figure 6.2 illustrates these measurements in dB/μV/m. The radiated power as determined from the "best fit" straight line through the data points is 20 kw. This is



STATION FREQ = 55.50 TLAT = 58.600 TLON = 3.667
GTS CALLAGHAN, TRIP 8 BAYONNE TO BREMERHAVEN
BEGIN : 05/31/85 AT 2300Z END : 06/06/85 AT 0900Z
DELTA dB 93.20 REFERENCE, TX

Figure 6.1 Log distance plot for cruise 8, used to calculate the radiated power for Thurso, Scotland, at 55.5 kHz.

102.5 = dB/μV/m at 10 km
-89.5 = dB for 1 kw
13.0 dB/kw = 20 kw radiated

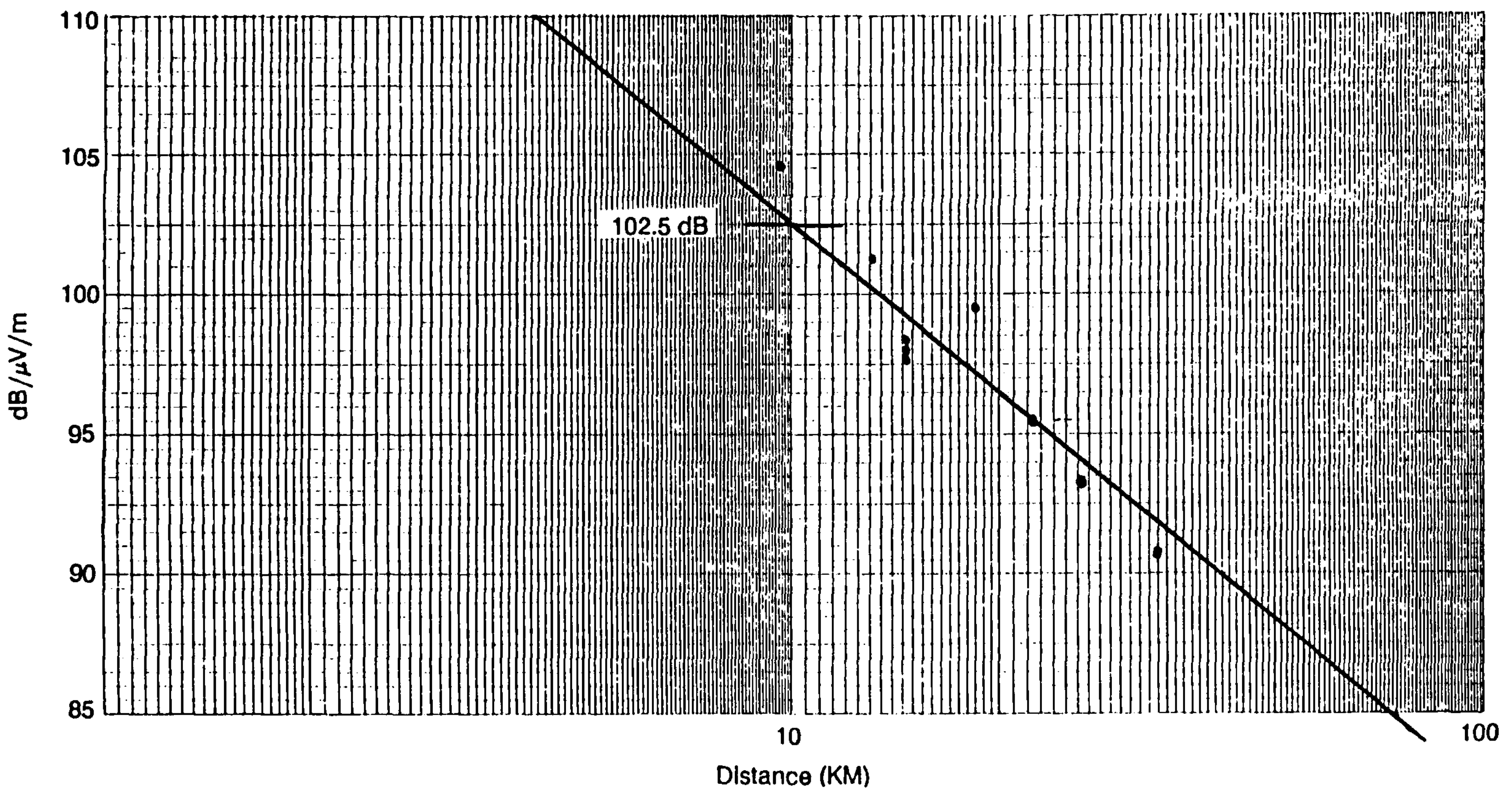


Figure 6.2 Near field radiated power measurements of Thurso, Scotland at 55.5 kHz. Measured 6/20/84

approximately 1.0 dB/kw higher than results obtained from the Callaghan data.

Cruise #	dB/μV/m at 100 km	dB/kw	kw
8	81.5	12.0	15.8
9	81.5	12.0	15.8
10	81.5	12.0	15.8
11	81.8	12.3	17.0
16	81.9	12.4	17.4
17	81.1	11.6	14.5
Average	81.55	12.05	16.0

Table 6.1 Radiated power for Thurso, Scotland at 55.5 kHz as measured from the GTS Callaghan.

Radiated power measurements were also made for several cruises in which the Callaghan was at a distance of between 75-200 km to transmitters located in Annapolis, MD and Driver, VA. The calculated radiated power during these close approaches, as well as the best available data on the transmitters radiated power, is listed in Table 6.2. The $\Delta\, dB$ value in column 9 is the dB difference between the calculated Callaghan average value and the "best available information" value obtained from [3] and [4]. As this data shows, the measured radiated power for the Annapolis transmitters on 21.4 and 51.6 kHz is within 1 dB of results obtained and discussed in [4]. For the Driver, VA data collected at 77.15 kHz, there is a 3.7 dB discrepancy between the measured power and the best available information (obtained from [3]). It is possible that this discrepancy is, in part, due to unreliable information in [3] on radiated power being used.

Freq (kHz)	Cruise #	dB/μV/m at 100 km	dB/kw	kw	Ave dB/μV/m	Ave kw	Best Info	ΔdB
21.4	3	92.7	23.2	208.9				
21.4	12	92.0	22.5	177.8	92.35	192.8	213.0 [a]	0.4
51.6	3	75.8	6.3	4.3				
51.6	12	75.0	5.5	3.5				
51.6	49	74.0	4.5	2.8	74.93	3.5	3.9 [a]	0.5
77.15	3	81.8	12.3	17.0				
77.15	12	81.6	12.1	16.2				
77.15	22	81.2	11.7	14.8				
77.15	49	80.0	10.5	11.2	81.15	14.6	35.0 [b]	3.7
88.0	3	75.2	5.7	3.7				
88.0	12	75.8	6.3	4.3				
88.0	49	73.0	3.5	2.2	74.67	3.3	5.3 [a]	2.1

Table 6.2 Radiated power deduced from field strength measurements made on the GTS Callaghan during close approaches to VLF/LF transmitters on the East coast of the U.S. [a] Best information obtained using [4]. [b] Best information obtained using [3].

6.2 Radiated Power Calculations from C-141 Data

As with the Callaghan, several C-141 flights made near approaches to VLF/LF transmitters. From these near approaches, it is possible to calculate the radiated power from the transmitters. The method used is exactly the same as for the Callaghan data. Figure 6.3 illustrates the log distance plot obtained during the September 18, 1985 flight for the 16.0 kHz transmitter located in Rugby, England. The radiated power measurements calculated from this and other similar data obtained during C-141 "fly-bys" is listed in Tables 6.3 (VLF radiated power) and 6.4 (LF radiated power). Table 6.5 compares C-141 and Callaghan radiated power results.

In Tables 6.3 and 6.4, the average dB/μV/m (column 6) is the average of the dB/μV/m values listed in column 3. The calculated average kw (column 7) is computed using the average dB/μV/m listed in column 6 and converting this value to kw. The ΔdB listed in column 9 is the dB difference between the average kw (column 7) and the radiated kw obtained from the "best information" available (column 8). Table.6.5 compares the log-distance method determination of radiated power deduced from C-141 vs Callaghan data, i.e., it compares the average data from Tables 6.3 and 6.4 with that from Table 6.2.

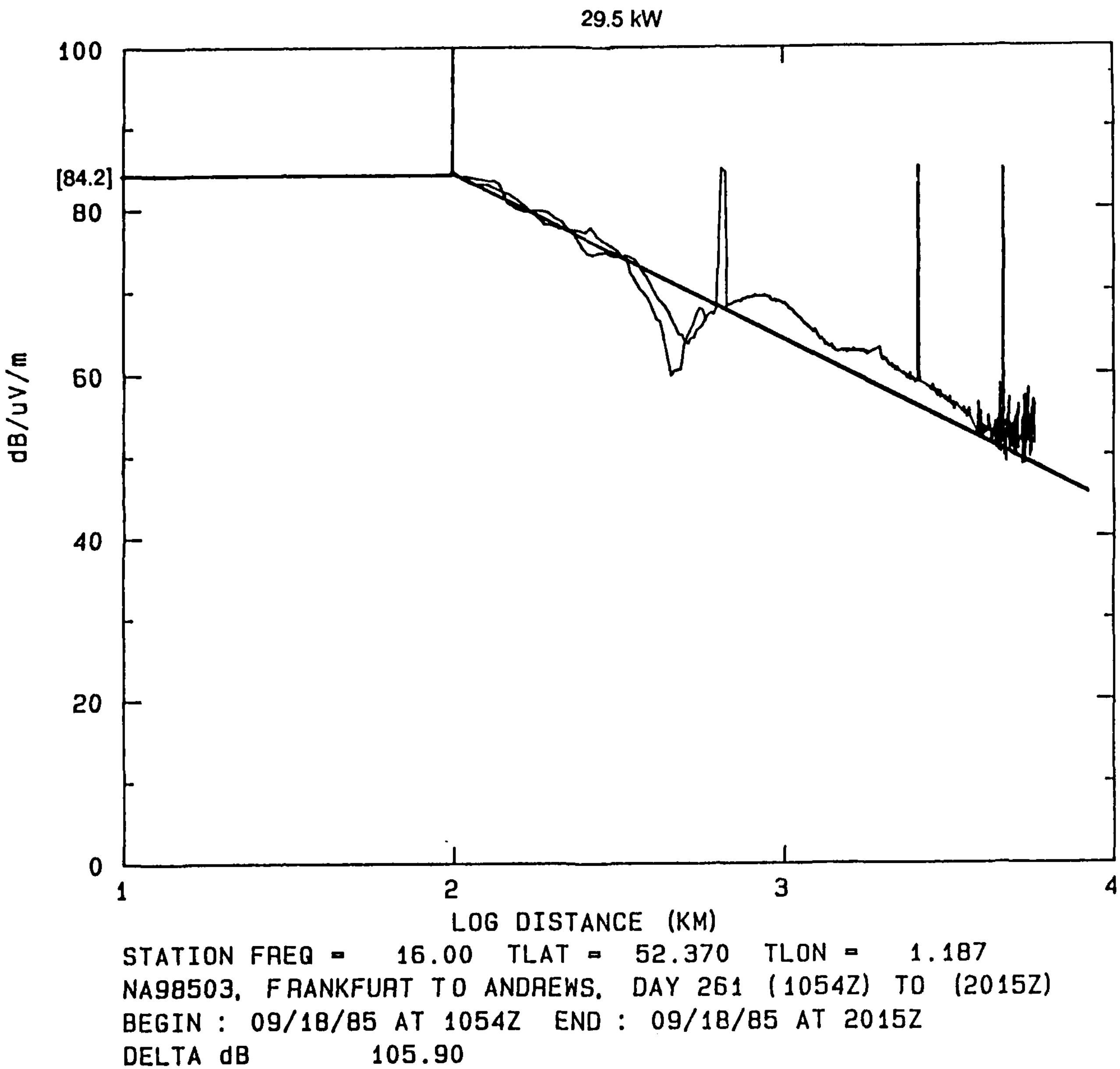


Figure 6.3 Log distance plot, flight 3 - Frankfurt to Andrews. Used to determine radiated power for Rugby, England at 16.0 kHz.

Freq (kHz)	Trip	dB/μV/m at 100 km	dB/kw	kw	Ave dB/μV/m	Ave kw	Best Info	$\Delta\, dB$
16.0	84-10	85.7	16.2	41.7				
16.0	84-03	84.2	14.7	29.5				
16.0	85-f17	86.5	17.0	50.1				
16.0	85-f18	84.5	15.0	31.6				
16.0	85-f20	86.5	17.0	50.1	85.5	39.8	65.0[b]	2.1
19.0	84-10	86.9	17.4	55.0				
19.0	84-13	86.0	16.5	44.7				
19.0	84-16	88.0	18.5	70.8				
19.0	85-f17	87.5	18.0	63.1				
19.0	85-f18	87.2	17.7	58.9				
19.0	85-f20	86.2	16.7	46.8				
19.0	85-s03	86.0	16.5	44.7	86.8	53.7	80.0[b]	1.7
21.4	84-03	92.0	22.5	177.8				
21.4	84-06	91.8	22.3	169.8				
21.4	84-09	91.3	21.8	151.4				
21.4	84-13	91.9	22.4	173.8				
21.4	84-17	93.0	23.5	223.9				
21.4	85-f02	91.0	21.5	141.0				
21.4	85-f04	92.0	22.5	177.8				
21.4	85-f05	91.8	22.3	170.0				
21.4	85-f15	92.5	23.0	199.5				
21.4	85-f16	92.7	23.2	208.9				
21.4	85-f19	93.2	23.7	234.4				
21.4	85-f20	92.0	22.5	177.8				
21.4	85-s04	91.5	22.0	158.5				
21.4	85-s07	92.7	23.2	208.9	92.1	182.0	213[a]	0.7
24.0	84-10	97.2	27.7	588.8				
24.0	84-11	95.0	25.5	354.8				
24.0	85-f05	95.4	25.9	389.0				
24.0	85-f07	96.5	27.0	501.2				
24.0	85-f15	96.8	27.3	537.0				
24.0	85-s03	95.5	26.0	398.1				
24.0	85-s07	96.0	26.5	446.7	96.1	457.1	750[b]	2.2

Table 6.3 VLF Radiated Power Measurements Deduced from C-141 Flight data. [a] Best information obtained using [4]. [b] Best information obtained using [3].

Freq (kHz)	Trip	dB/μV/m at 100 km	dB/kw	kw	Ave dB/μV/m	Ave kw	Best Info	$\Delta\, dB$
51.6	84-03	73.3	3.8	2.4				
51.6	84-06	75.0	5.5	3.5				
51.6	84-09	75.5	6.0	4.0				
51.6	84-13	75.2	5.7	3.7				
51.6	84-17	76.0	6.5	4.5				
51.6	85-f02	73.7	4.2	2.6				
51.6	85-f04	77.2	7.7	5.9				
51.6	85-f05	76.9	7.4	5.5				
51.6	85-f15	75.6	6.1	4.1				
51.6	85-f16	76.3	6.8	4.8				
51.6	85-f19	75.6	6.1	4.1				
51.6	85-f20	74.9	5.4	3.5	75.4	3.9	3.9[a]	0.0
57.4	85-f02	79.0	9.5	8.9				
57.4	85-f05	79.5	10.0	10.0				
57.4	85-f07	77.2	7.7	5.9				
57.4	85-f08	76.7	7.2	5.2	78.1	7.2	-	-
77.15	85-f02	81.0	11.5	14.1				
77.15	85-f04	78.8	9.3	8.5				
77.15	85-f05	78.8	9.3	8.5				
77.15	85-f16	84.0	14.5	28.2				
77.15	85-f19	81.3	11.8	15.1				
77.15	85-f20	79.5	10.0	10.0	80.6	12.9	35.0[b]	4.3
88.0	84-03	74.5	5.0	3.2				
88.0	84-06	74.5	5.0	3.2				
88.0	84-09	74.8	5.3	3.4				
88.0	84-13	75.5	6.0	4.0				
88.0	84-17	75.0	5.5	3.5				
88.0	85-f02	74.5	5.0	3.2				
88.0	85-f04	77.0	7.5	5.6				
88.0	88-f05	75.3	5.8	3.8				
88.0	88-f16	75.4	5.9	3.9				
88.0	85-f19	75.5	6.0	4.0				
88.0	85-s04	75.2	5.7	3.7				
88.0	85-s07	77.0	7.5	5.6	75.4	3.9	5.3[a]	1.3
134.9	84-03	77.5	8.0	6.3				
134.9	84-06	76.5	7.0	5.0				
134.9	85-f02	77.5	8.0	6.3				
134.9	85-f05	78.2	8.7	7.4				
134.9	85-s04	76.9	7.4	5.5				
134.9	85-s07	80.0	10.5	11.2	77.8	6.8	-	-
142.25	84-02	80.8	11.3	13.5				
142.25	84-03	81.0	11.5	14.1				
142.25	84-08	80.2	10.7	11.7				
142.25	85-f02	80.0	10.5	11.2				
142.25	85-f05	81.3	11.8	15.1				
142.25	85-f07	79.9	10.4	11.0				
142.25	85-f08	78.9	9.4	8.7	80.3	12.0	-	-

Table 6.4 LF Radiated Power Measurements Deduced from C-141 Flight data. [a] Best information obtained using [4]. [b] Best information obtained using [3].

Frequency (kHz)	Callaghan kw	C-141 kw	kw Difference	dB Difference
21.4	192.0	182.0	10.0	0.25
51.6	3.5	3.9	0.4	0.47
77.15	14.9	12.9	2.0	0.55
88.0	3.3	3.9	0.6	0.73

Table 6.5 Comparison of radiated power measurements made on the Callaghan versus measurements made on C-141 aircraft.

SECTION 7 - SIMULTANEOUS AIRCRAFT/SHIP DATA

During the September, 1985 C-141 aircraft flights 2 and 3, the aircraft flew very close to the Callaghan, allowing the recording of simultaneous signal data in the same operating area. Figures 7.1 and 7.2 illustrate the tracks taken during cruise 20 and flights 2 (9/17/85) and 3 (9/18/85), respectively, when both recording platforms were in the same operating area. During flight 2, the closest approach to the ship occurred during the period 1400-1430 (GMT), at a distance of 146 km. During flight 3, the closest approach to the ship occurred during the period 1130-1200 (GMT), at a distance of 292 km.

To analyze this data, time plots were made of the ship and aircraft data for the time period during which the aircraft made its closest approach to the Callaghan. To determine the dB difference between the C-141 and Callaghan data during the time periods given above, a computer program was written which averaged all data points within the specified time periods. Figure 7.3 illustrates the time plot obtained for 16.0 kHz on 9/17/85 (flight 2). The time period 1400 to 1430 (GMT) was used to compare the signal level received on the aircraft with that received on the ship. This plot shows that the normalized ship and aircraft data differ by 10.0 dB. This difference is due to modal interference. To illustrate this, Figure 7.4 is a prediction of the signal strength along the path from Rugby, England (16.0 kHz) through the position of the ship/aircraft. This curve shows a difference of 9.2 dB between the ship (S1) and the aircraft (A1) predicted amplitudes, with the ship having a higher level than the aircraft.

Tables 7.1 and 7.2 list the distances of the Callaghan and C-141 aircraft from the transmitters, the predicted dB differences between the aircraft and ship positions, the average dB differences for several transmitters where simultaneous signal data was recorded, and the dB difference between predicted differences and actual measured differences. Table 7.1 lists these data for the Callaghan during trip 20 and the C-141 aircraft flight 2. Table 7.2 lists these data for trip 20 of the Callaghan and C-141 flight 3.

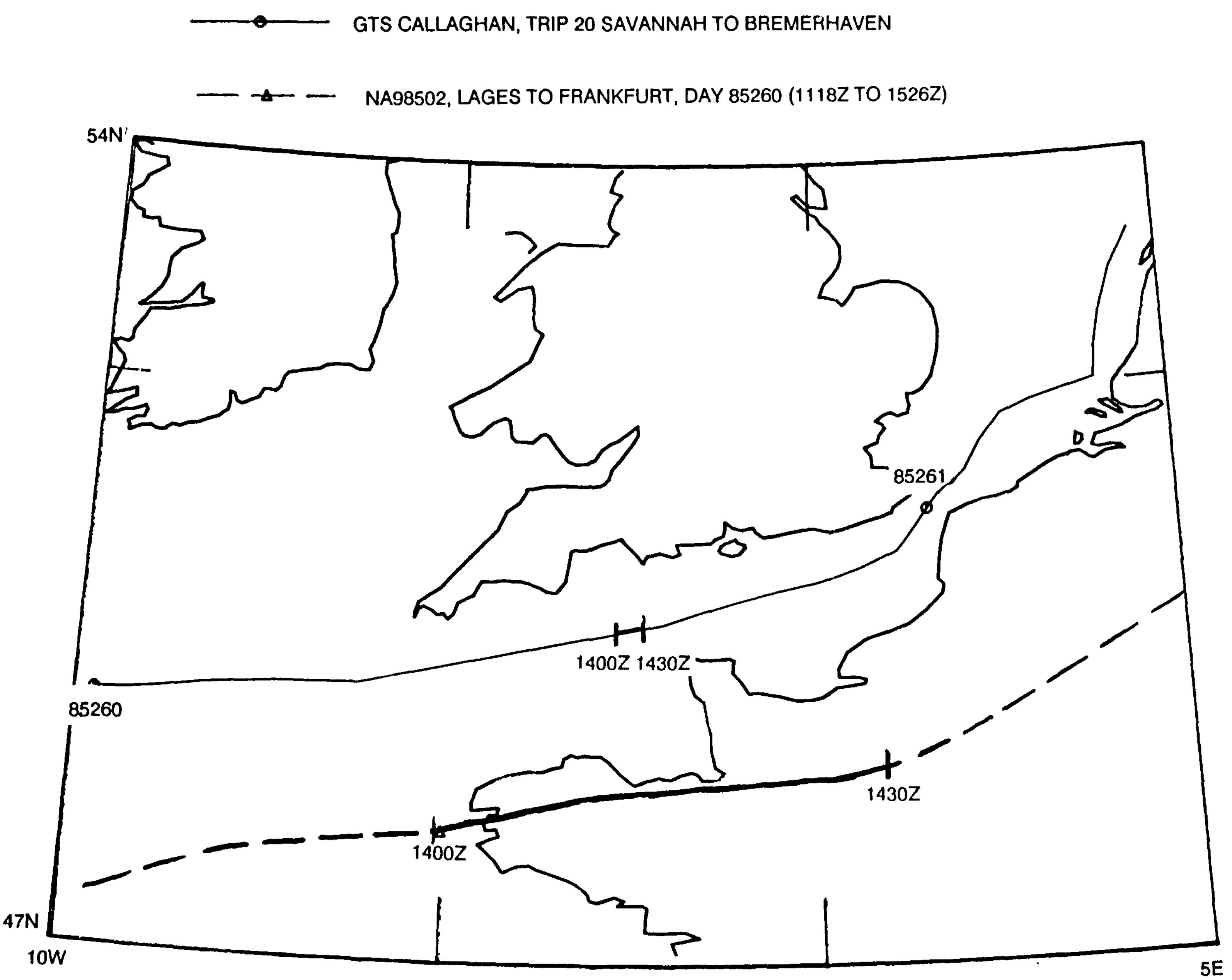


Figure 7.1 Navigational tracks used by the GTS Callaghan (cruise 20) and C-141 Aircraft (flight 2).

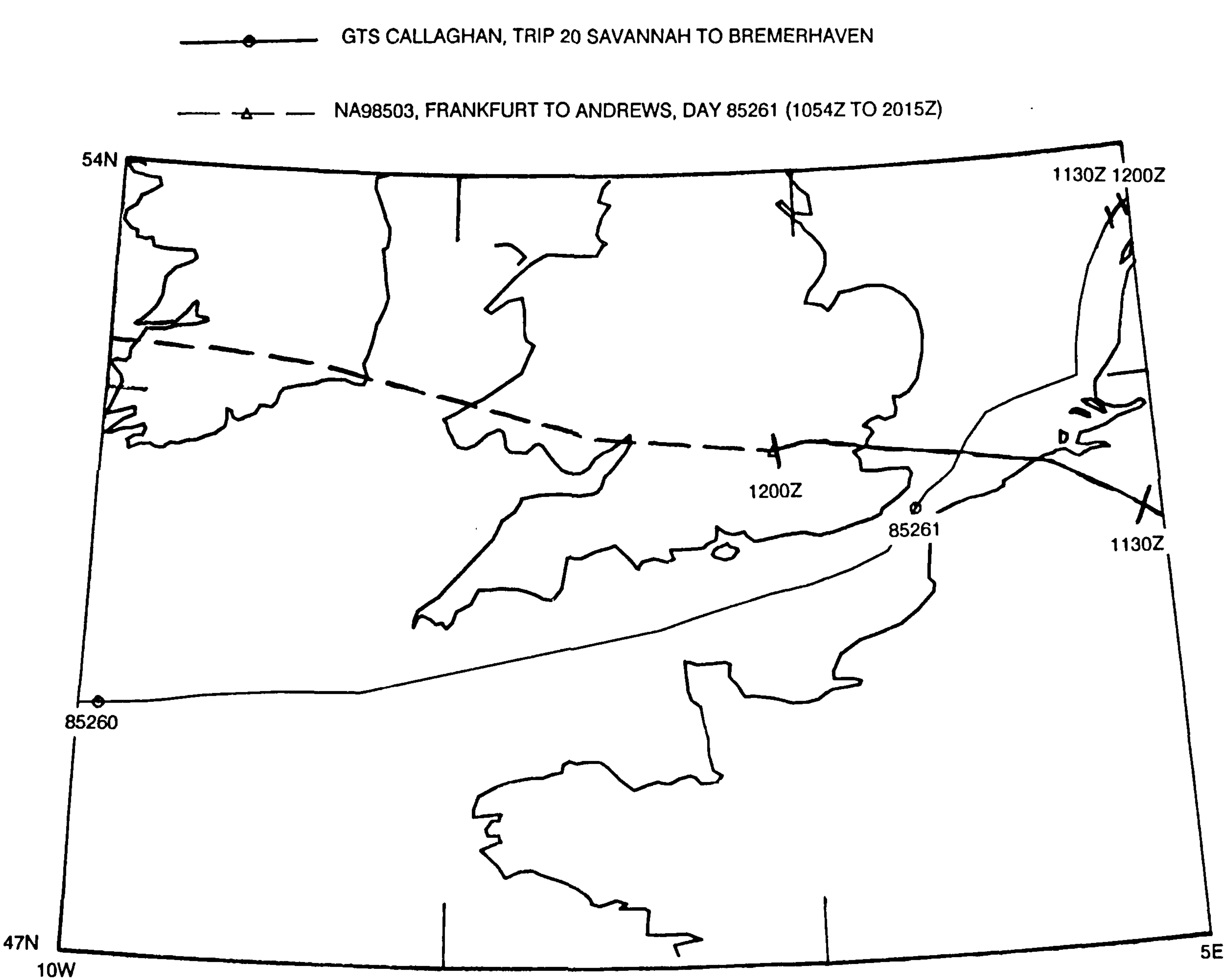


Figure 7.2 Navigational tracks used by the GTS Callaghan (cruise 20) and C-141 Aircraft (flight 3).

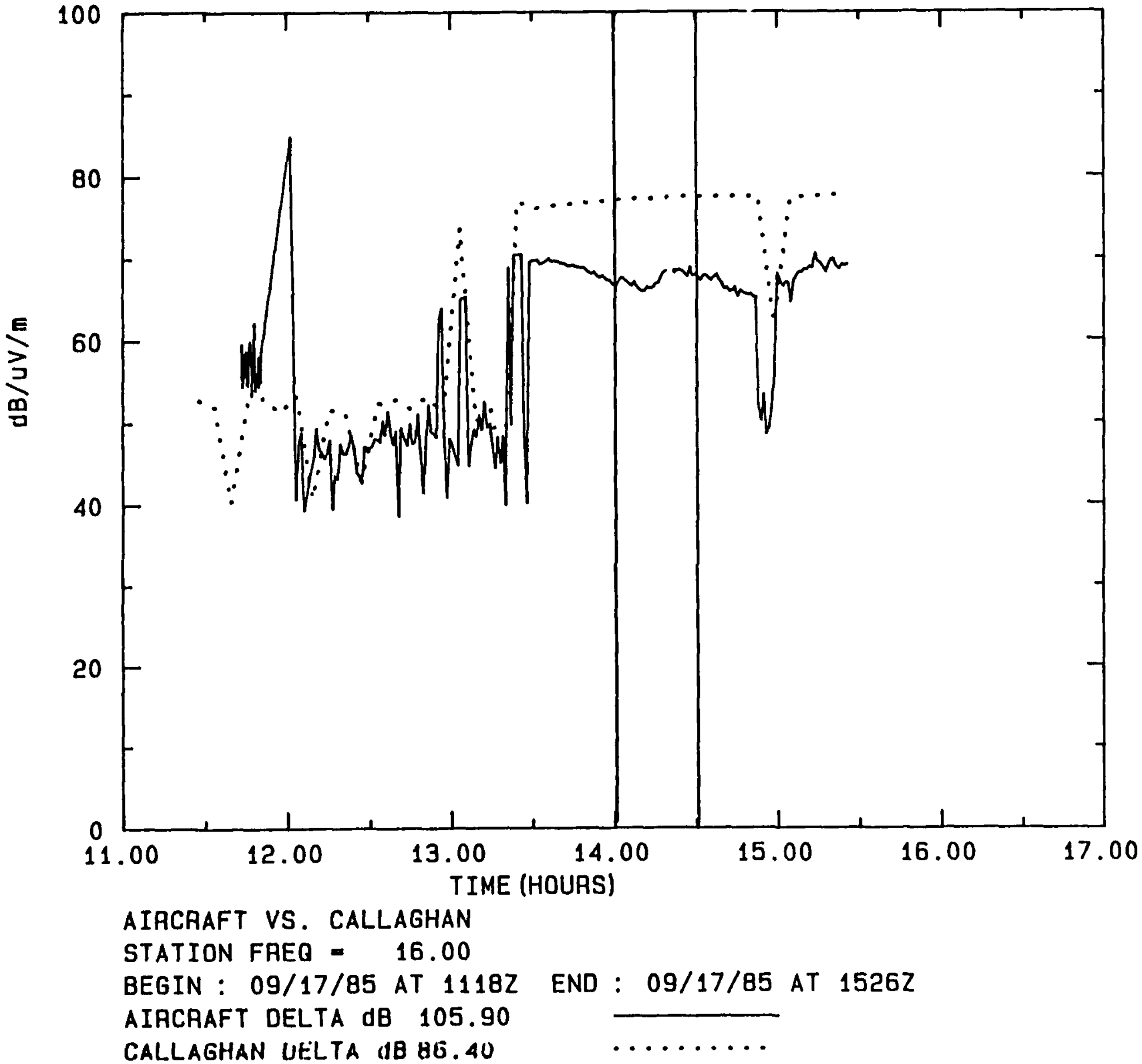
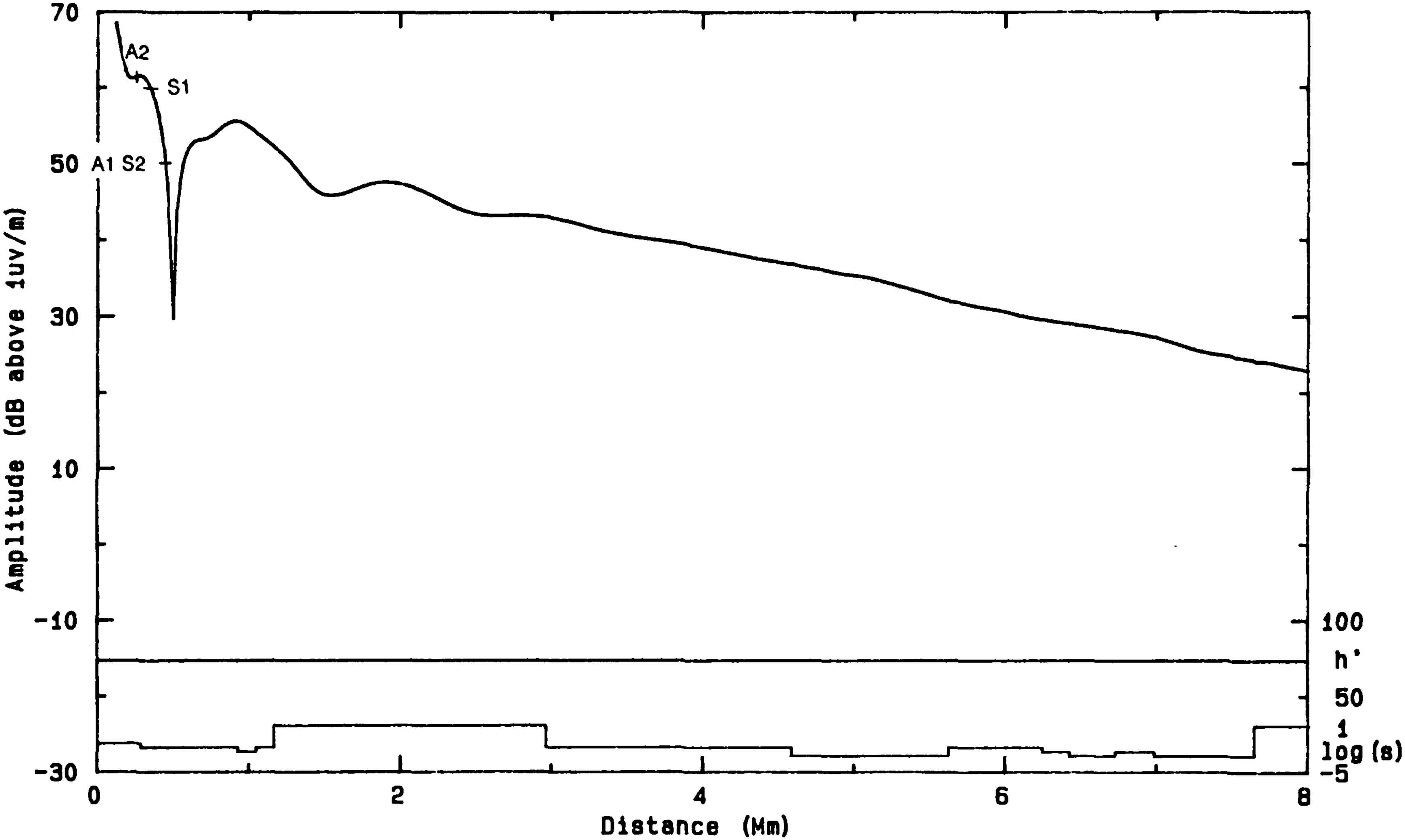


Figure 7.3 Simultaneous VLF/LF signal data collected on the GTS Callaghan (cruise 20) and C-141 aircraft (flight 2). The frequency monitored was located at Rugby, England, and was broadcasting at 16.0 kHz.



rugby to dover
xmtr_id freq tlat tlon brng pwr in hdg talt ralt
rug_dov 16.0 52.4 1.2 136.0 1 0 0.0 0.0 0.0
Prfl: All day

Figure 7.4 NOSC propagation prediction curve for 16.0 kHz along the path from Rugby, England to the nearest apprcach of the Callaghan and C-141 aircraft (September, 1985 flight 2).
A1 = C-141 flight 2, S1 = Callaghan cruise 20 Julian day 85260.
A2 = C-141 flight 3, S2 = Callaghan cruise 20, Julian day 85261.

Frequency (kHz)	Distance (MM) from		Predicted dB Diff.	Measured dB Diff.	dB Difference
	Ship	Aircraft			
16.0	0.3654	0.4533	9.2	10.0	0.8
16.4	2.1785	2.2728	0.6	3.5	2.9
19.0	0.5936	0.7186	-8.5	-11.5	-3.0
21.4	5.6581	5.7665	0.2	0.0	-0.2
24.0	4.6763	4.7870	0.3	1.8	1.5
28.5	6.5400	6.5955	0.0	0.7	0.7

Table 7.1 Simultaneous Callaghan and C-141 Signal Data. Cruise 20, Flight 2.

Frequency (kHz)	Distance (MM) from		Predicted dB Diff.	Measured dB Diff.	dB Difference
	Ship	Aircraft			
16.4	1.5631	1.8523	0.8	0.4	-0.4
19.0	0.5770	0.5257	-8.7	-16.8	-8.1
21.4	6.1265	5.9978	0.0	0.5	0.5
24.0	5.1400	5.0114	-0.4	-0.3	0.1
28.5	7.2207	6.9830	0.0	2.2	2.2
55.5	0.7895	0.8777	1.2	1.0	-0.2

Table 7.2 Simultaneous Callaghan and C-141 Signal Data. Cruise 20, Flight 3.

The dB difference presented in Tables 7.1 and 7.2 (columns 4 and 5) is positive when the measured (or predicted) signal level on the ship is greater than that measured by the aircraft. It is negative when the aircraft signal level is higher than the ship. The dB difference listed in column 6 of Tables 7.1 and 7.2 is the difference between the measured dB difference (column 5) and the predicted dB difference (column 4).

This data gives further indication of the accuracy of the calibrations performed on both the aircraft and the ship. The only times in which the dB difference between ship and aircraft measured data (column 5) is large is when the platforms are in an area of predicted modal interference. The propagation prediction programs are not as accurate in these areas. Appendix D contains the simultaneous time plots used in determining the dB differences presented in Tables 7.1 and 7.2, as well as plots of the predicted signals.

SECTION 8 - PROBLEMS ENCOUNTERED

Several problems occurred with the antenna and preamplifiers during the data collection period described in this report. These problems are discussed below.

8.1 Antenna Failure

At the conclusion of cruise 9, while the Callaghan was in port at Bayonne, NJ the six foot metal telescoping antenna in use was accidentally broken in half. The Callaghan made seven cruises (10 to 16) with this shortened antenna. Before the antenna was replaced, a calibration of the ship was made (Section 4) in order to convert the data recorded with the shortened antenna to absolute field intensity. The antenna was replaced with an eight foot fiber-glass whip antenna. There were no further problems with the antennae.

8.2 Preamplifier Difficulties

The preamplifiers used on the Callaghan were found to have several problems: 1) The calibration circuits were found to be very unstable on preamps serial #1 and #2; 2) All three preamplifiers would become "saturated" when operating near strong transmitters; and 3) Preamplifiers numbered 1 and 2, and the C-141 preamplifier may not have always been atmospheric noise limited.

8.2.1 Unstable Calibration Circuits

A calibration signal is injected into the preamplifier, using the F_o 0 dBm tracking signal supplied from the HP 3586C, through a 5 pF capacitor to the input of the first transistor amplifier stage. The F_o 0 dBm tracking signal has an accuracy of ± 0.5 dB. Thus, any drift of greater than this is most likely the result of an unstable calibration circuit, preamp gain, or antenna losses (a dirty and/or wet antenna insulator). The first preamplifier used on the Callaghan (serial #2) exhibited drifts of up to 13 dB in calibration readings and was replaced with preamplifier serial #1. Figure 8.1 illustrates the drift experienced with preamplifier #2 from 3/1/85 (85060) to 6/09/85 (85160). The gain stability of preamplifier serial #1 was also found to be unstable and was replaced with preamplifier serial #8.

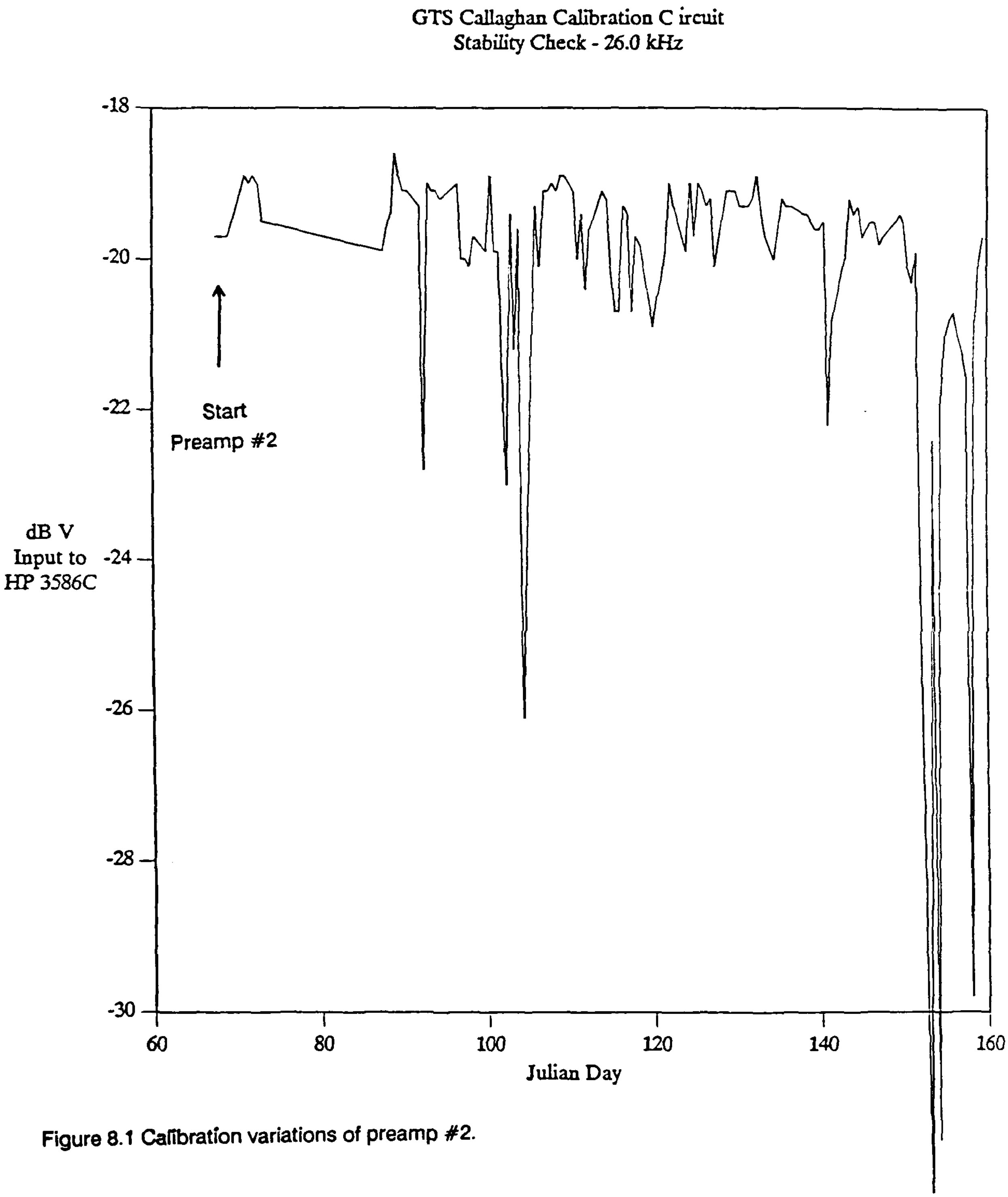


Figure 8.1 Calibration variations of preamp #2.

Preamplifier #8 was used for the remainder of the project. Its calibration remained relatively stable, drifting less than 2 dB. Appendix E contains plots of the calibration stability for the entire data collection period on the Callaghan.

Although the calibration circuits for preamps #1 and #2 were found to be unstable, the recorded signal data did not show any signs of similar random variation. Based on an analysis of the signal data, it is believed that only the calibration circuit was faulty, not the entire preamp or antenna system. The recorded signal data does not appear to have been affected by the faulty calibration circuit.

8.2.2 Observed LF Signal Distortion

The LF data recorded during C-141 flights, and on the Callaghan, appeared to be affected by a strong transmitter or signal source near Europe. Upon analysis of the data, it does not appear that data recorded at VLF was affected by this phenomenon. However, at LF this phenomenon was very evident.

Figure 8.2 illustrates this phenomenon recorded aboard the C-141 aircraft. This plot shows the signal strength decreasing with distance from the 77.15 kHz transmitter (Driver, VA). When the aircraft reaches a distance of 4.5 mm from the transmitter, the recorded level begins rising. This phenomenon occurred at several other frequencies (from 51.6 kHz to 134.9 kHz) and is not believed to have been caused by a transmitter operating on the same frequency as Driver. This phenomenon has been documented in [4]. It only occurred as the aircraft approached Europe. Therefore, it is recommended that no LF data from the following transmitters: 51.6, 77.15, 88.0, and 134.9 kHz, collected farther than 4.5 mm from the transmitter, be used for propagation or noise analysis.

The same phenomenon was also found to exist on the Callaghan. Figure 8.3 illustrates this at 51.6 kHz during cruise 17. At a distance of 4.8 mm from the Annapolis transmitter, the recorded signal begins to increase as Europe is approached. Due to this phenomenon, it is recommended that any LF data collected farther than 4.5 mm from the respective east coast transmitter not be used for propagation analysis. There does not appear to have been a similar problem with VLF signal data

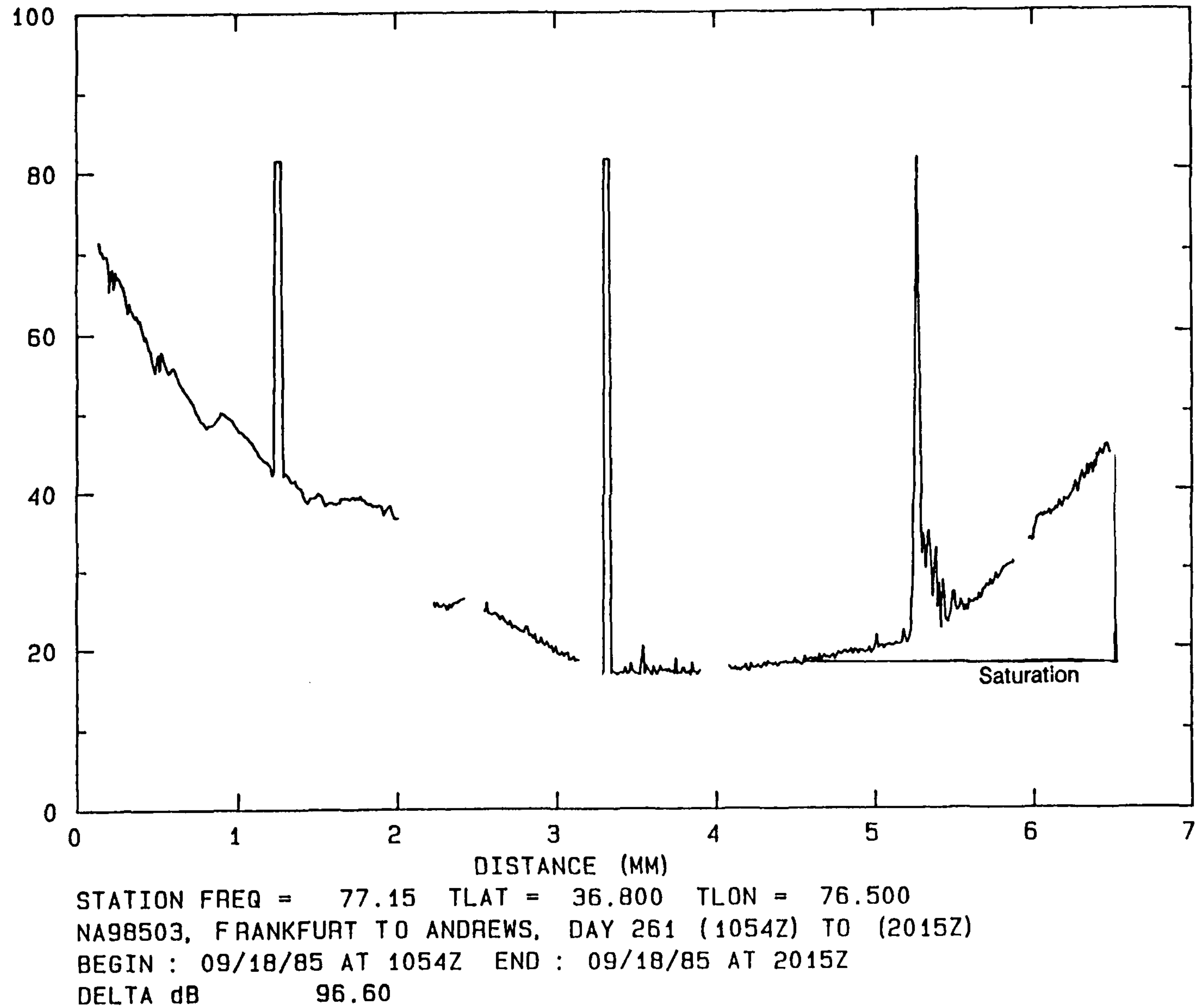


Figure 8.2 C-141 preamplifier saturation near Europe for preamp #3.

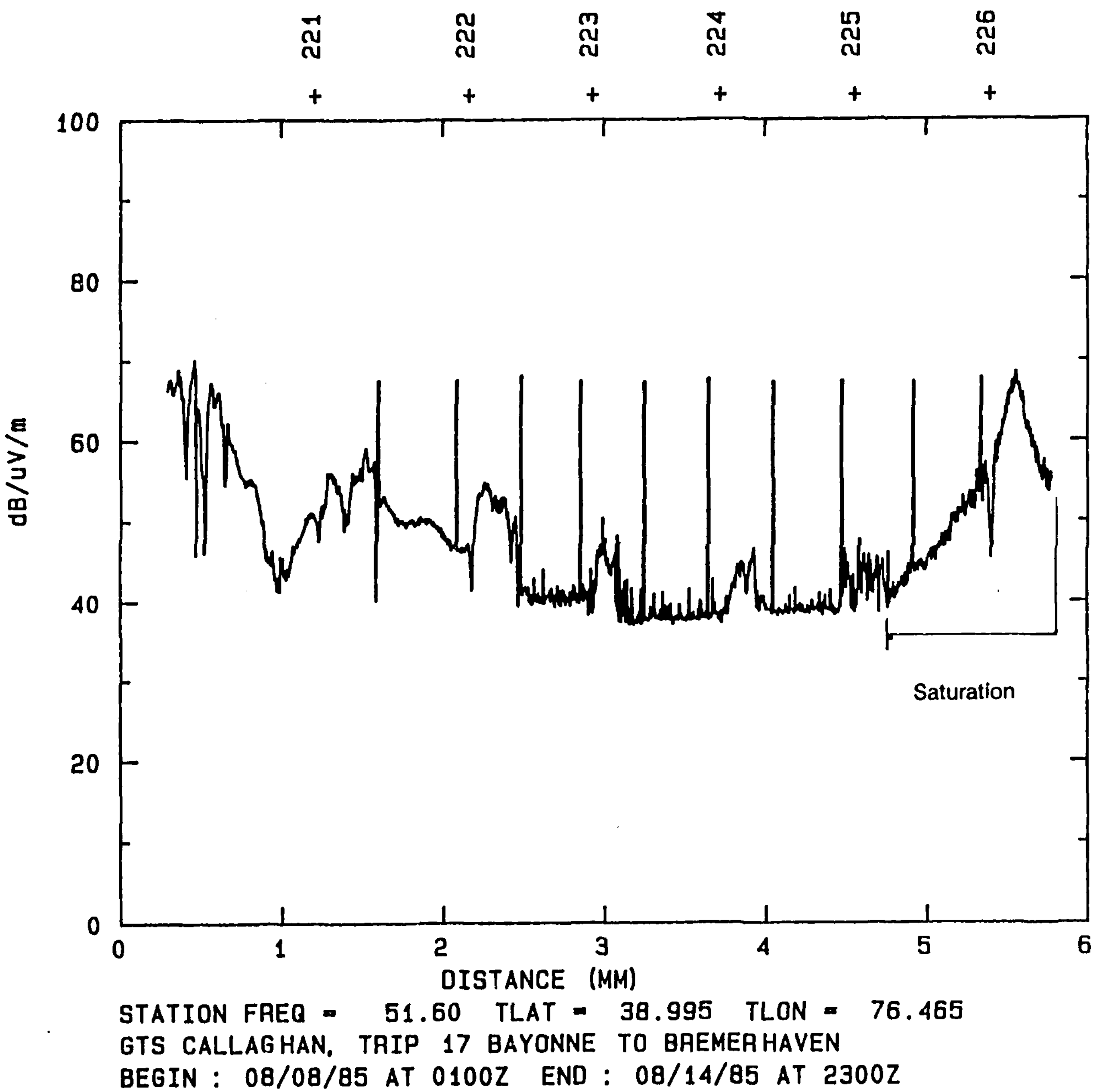


Figure 8.3 GTS Callaghan preamplifier saturation near Europe for preamp #2.

recordings. NOSC is currently investigating the exact cause of this phenomenon.

8.2.3 Preamplifier Thermal Noise Limitations

To determine if the actual thermal noise generated by the preamplifiers interferes with the recording of weak signals or atmospheric noise, one needs to calculate its equivalent noise field intensity, N_{pa}. This can be calculated using the following equation:

$$N_{pa}(\mathrm{dB}) = (120.0 + \mathrm{dB}V_N) - \mathrm{Site}\ \Delta\mathrm{dB}.$$

Where:

$\mathrm{dB}V_N$ = the measured noise floor of the preamp at a given frequency (in dBV), and

Site ΔdB = the calibration factor (ΔdB) for a given frequency (Figures 4.5 to 4.9).

For example, to calculate the noise floor for preamp #8 at 26.0 kHz, using Figure 8.4 (noise plot for preamp #8) the $\mathrm{dB}V_N$ value of the preamp is -81.1, and the ΔdB correction factor (Figure 4.8) is 34.8 dB/μV/m. Thus, the noise generated by preamplifier #8 at 26.0 kHz is, for the 400 Hz bandwidth used, equivalent to a noise field at the antenna of 4.1 dB/μV/m. Table 8.1 lists the lower limits of noise, in dB/μV/m picked up by the antenna system, for the three preamplifiers used on the Callaghan, as well as the preamplifier used during C-141 flights.

PREAMPLIFIER	26.0 kHz	63.0 kHz	140.0 kHz
C-141 Preamp #3	22.8	17.6	19.8
Callaghan Preamp #2 (a)	18.1	15.0	12.3
Callaghan Preamp #2 (b)	23.4	20.4	17.6
Callaghan Preamp #1	9.0	5.6	4.6
Callaghan Preamp #8	4.1	0.2	-0.3

Table 8.1 NOSC VLF/LF preamplifier thermal noise lower limits in dB/μV/m for a 400 Hz bandwidth. The following antenna types were used: Preamp #3 - Hatch blade antenna, Preamp #2a - 6 foot metal antenna, Preamp #2b - 3 foot metal antenna, Preamps #1 and #8 - 3 foot fiberglass whip antenna.

The data presented in Table 8.1 should be considered as the lower limit on receivable noise data with the current NOSC measuring equipment. Other factors, such as man made noise, as can be found on both aircraft and ships, can increase these minimal values considerably.

Figure 8.5 illustrates noise data collected on the Callaghan during cruise #1 (3/29/85 to 4/06/85) at 26.0 kHz. The lower limit on receivable noise, at 26.0 kHz, with preamp #2a is 18.1

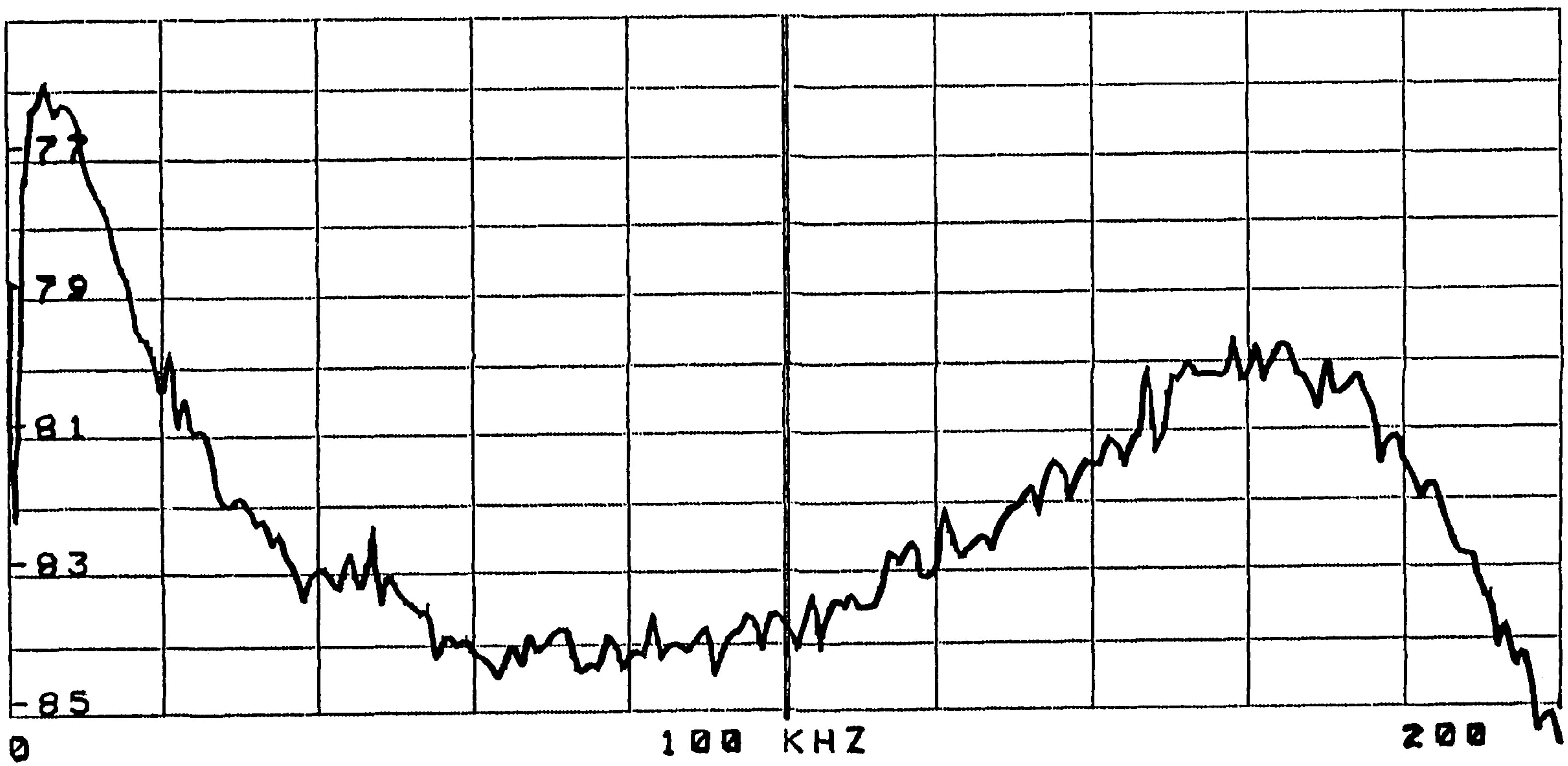


Figure 8.4 VLF/LF preamplifier noise floor, in dBV, for preamplifier serial #8.

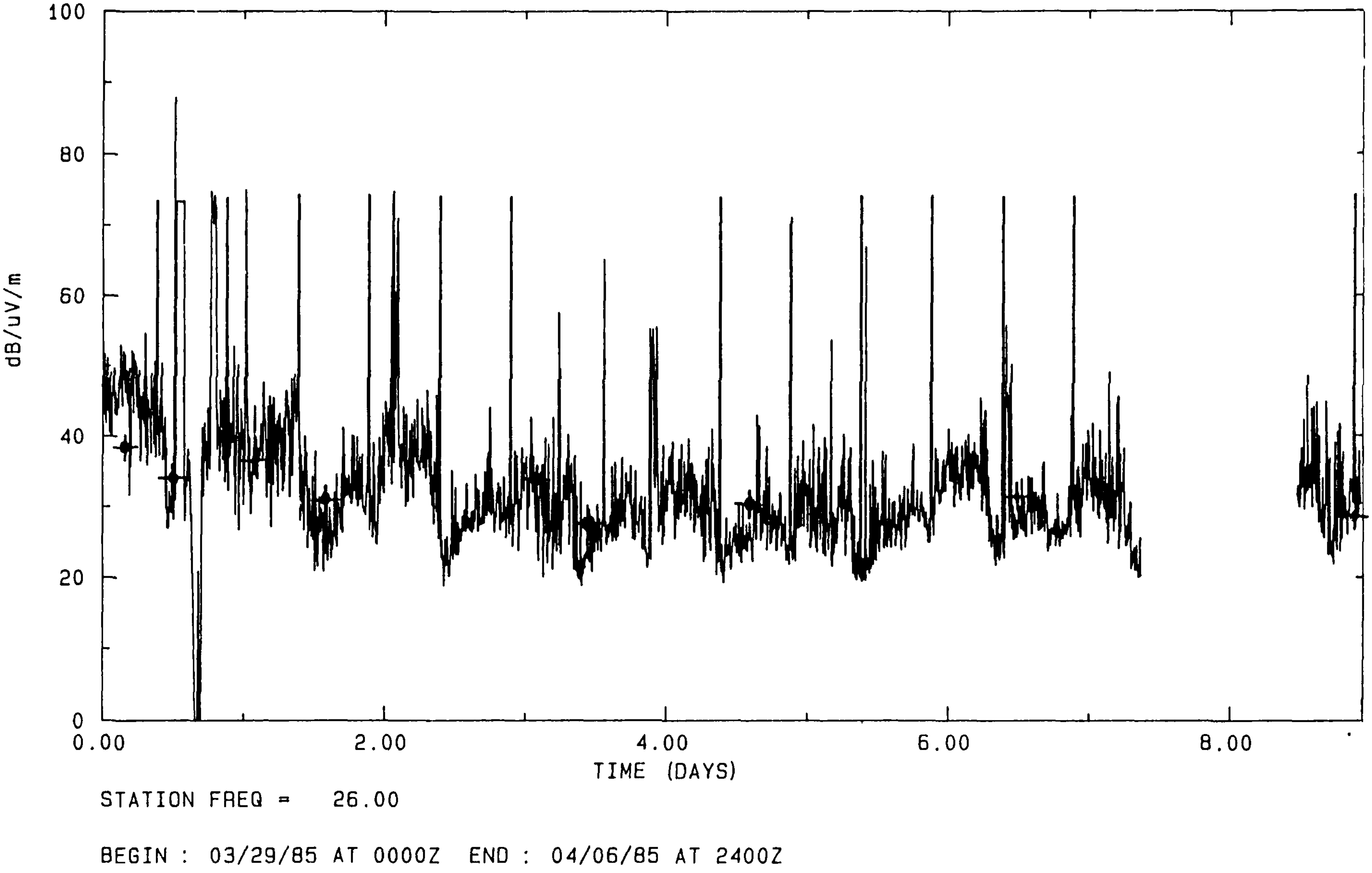


Figure 8.5 Callaghan noise data at 26.0 kHz, cruise #1. DECO noise prediction levels =

dB/μV/m in the 400 Hz bandwidth of the HP3586C (Table 8.1). The collected noise data is at least 3 dB above the preamplifiers noise floor. Figure 8.5 indicates the predicted atmospheric noise level as calculated using the DECO "VLF ATMOSPHERIC NOISE PREDICTIONS" paper [10]. The predicted values, denoted by a "+", indicate that the measured noise levels are in close agreement with predicted values. Appendix F contains the noise data collected on the Callaghan. This data is plotted as a function of time only.

Based on a limited analysis of this data it appears that the noise data collected on the Callaghan, at VLF, during cruises 1 to 9 may be atmospheric noise limited. However, with data collected at LF during cruises 1 to 9, as well as all data collected on cruises 10-58, there are indications that either the noise floor of the preamps was limiting the data (as is the case at LF during cruises 1-9), or some man made noise was raising the noise floor of the system (as appears to occur during cruises 10-58), reducing the overall system sensitivity. Figure 8.6 illustrates the measured noise level at 63.0 kHz during cruise 17. As shown in Table 8.1, the noise floor of preamp 1 (used during cruise 17) is calculated at 5.6 dB/μV/m. This is well below the measured noise exhibited in Figure 8.6. The CCIR predicted noise levels are also displayed on the graph. This shows that the predicted noise level, at 63 kHz, is between 10 and 25 dB/μV/m lower than the measured noise level during cruise 17. An increase in noise during cruises 10-58 could be due to a change in the grounding system used on the Callaghan after preamp #2 was replaced by preamp #1 and then preamp #8, causing noise generated on the ship itself to become significant.

The C-141 aircraft noise data (appendix F) indicates that some of it is limited by the preamplifiers noise floor. Figures 8.7 and 8.8 illustrate noise data collected during flight 3 at 26.0 kHz and 63.0 kHz, respectively. Figure 8.7 shows the measured noise level at 26.0 kHz as well as the DECO predicted noise levels. The measured noise levels are in close agreement with the DECO predicted noise levels. However, at 63.0 kHz (figure 8.8) the measured noise level is approximately 7 dB higher than noise values predicted by the CCIR report during the first half of the flight. The CCIR prediction model was used for 63 kHz because the DECO report is only of use at VLF, not LF. Only at the end of the flight, as the aircraft was approaching Andrews AFB, is the measured

noise data in agreement with the CCIR predicted noise levels. These measured noise values are only 0.4 to 1.2 dB higher than the measured preamp thermal noise from Table 8.1. It appears that the noise data collected during C-141 flights at LF may not be atmospheric noise limited and should not be used in noise model analysis.

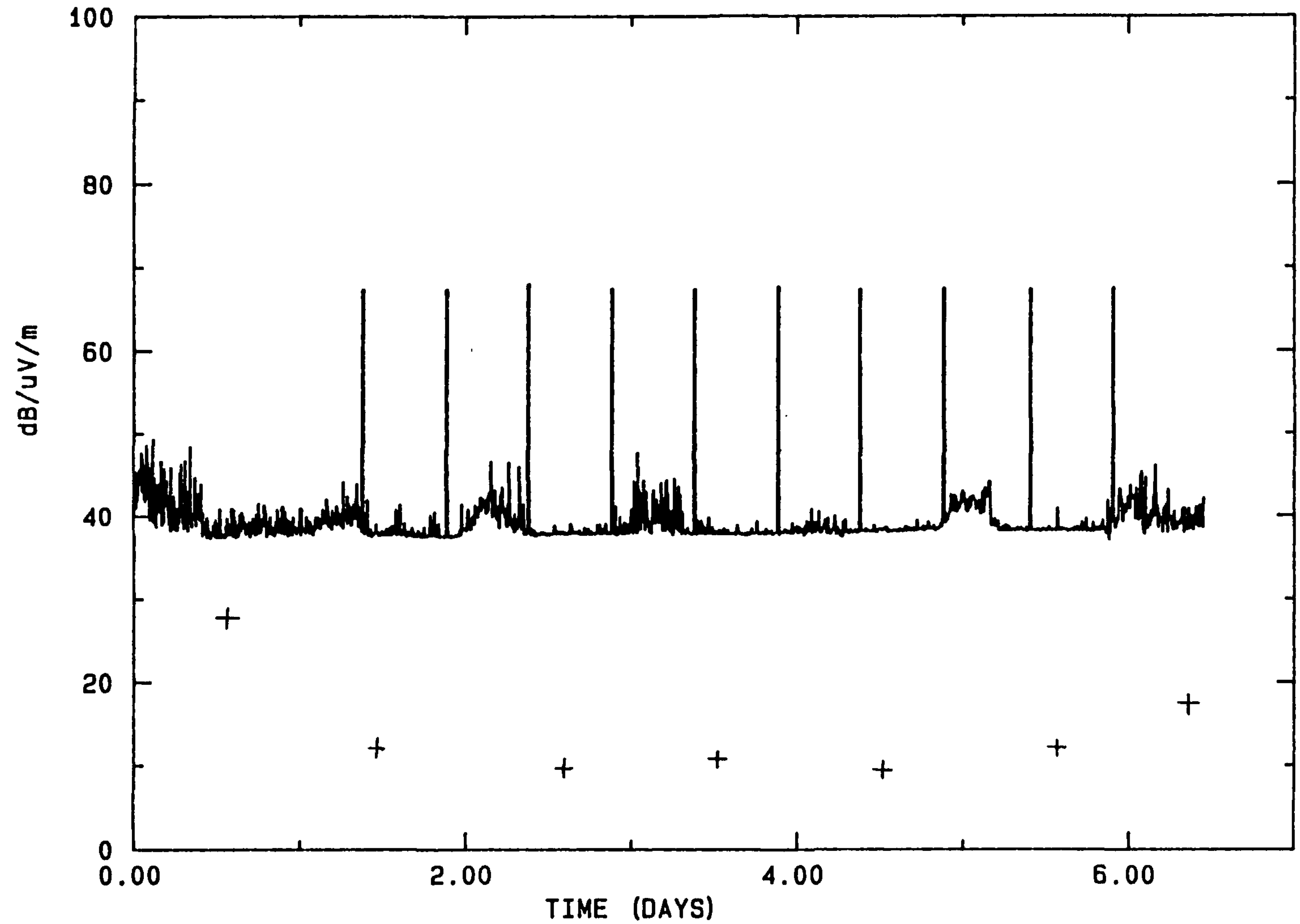


Figure 8.6 Measured noise level at 63.0 kHz during GTS Callaghan cruise 17. CCIR noise prediction values denoted by a "+".

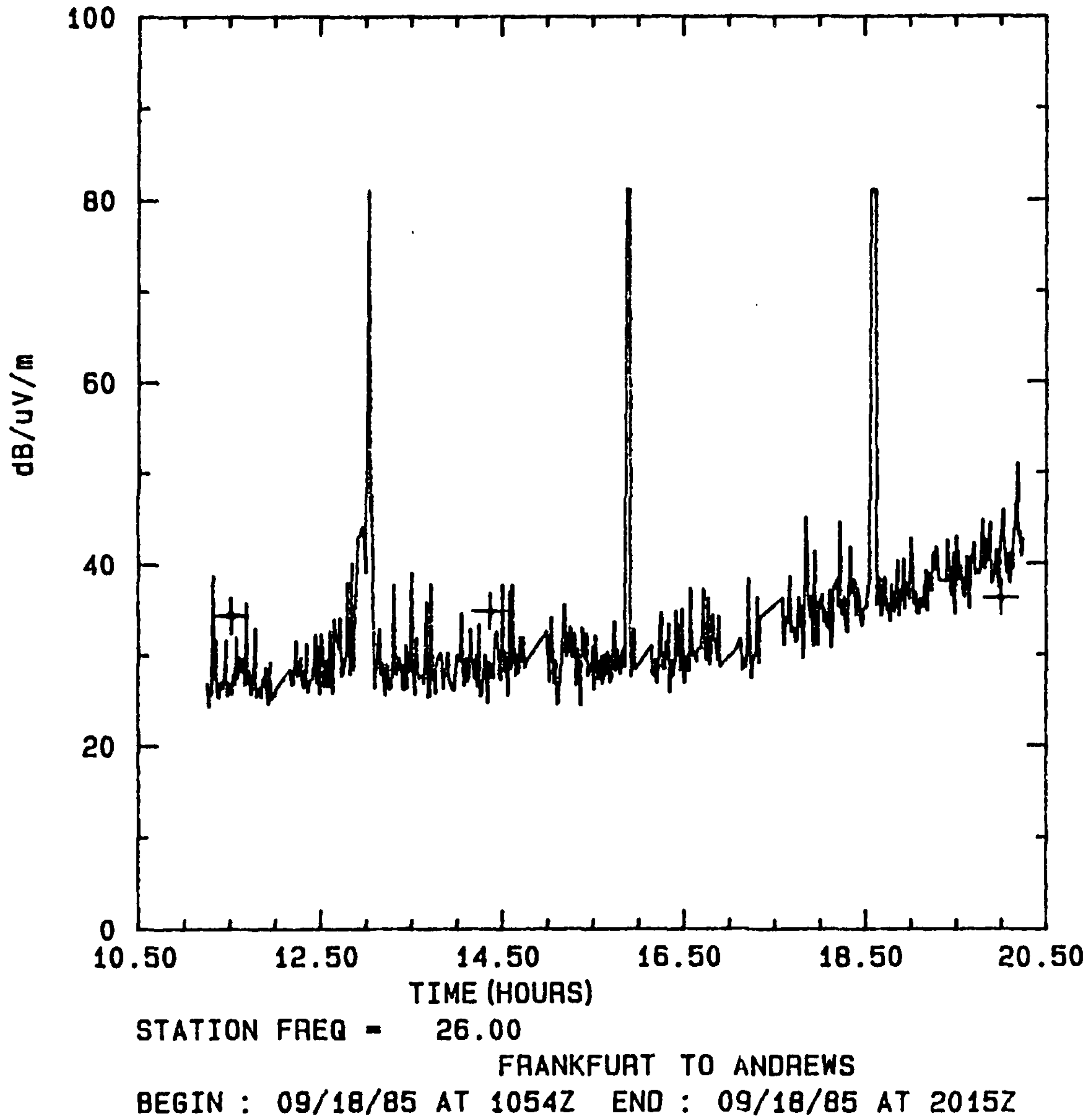


Figure 8.7 C-141 noise data during flight 3 (1985), at 26.0 kHz. DECO noise prediction levels denoted by a "+".

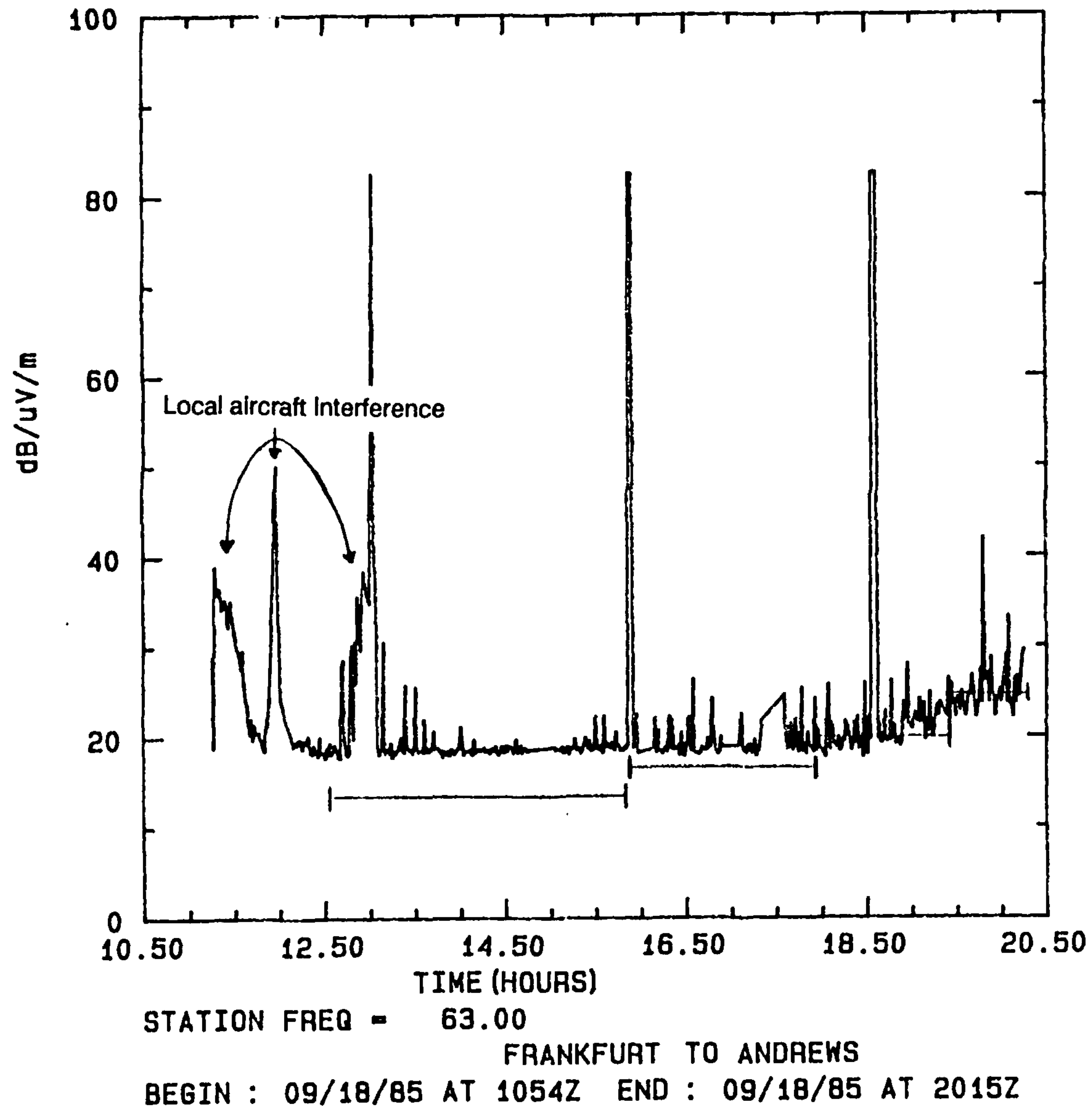


Figure 8.8 C-141 nosie data during flight 8 (1985), at 63.0 kHz. CCIR noise prediction levels denoted by a " ├──┤ ".

SECTION 9 - ACCURACY OF VLF/LF C-141 AND CALLAGHAN DATA

The accuracy of the normalized VLF/LF signal data recorded on the Callaghan and C-141 aircraft is dependent on a number of factors. These include the stability of the recording equipment (HP-3586C and VLF/LF Preamplifiers) and the accuracy with which it is calibrated. Calibration accuracy is dependent on the calibration equipment, and perturbations of the field measured at calibration sites. The "TRANS-CONUS 86 VLF/LF Data Acquisition Project" report [4] details the accuracy of the recording equipment and the calibration methodologies used. From this data, it has been found that the overall RMS uncertainty is approximately $\pm$ 1.3 dB when operating in a relatively noise free environment. When the recording system is operating in a high noise environment, or near a very strong transmitter, as discussed in Section 8.2.2, the data recorded is not believed to be reliable, and therefore should not be used in propagation analysis.

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3. Grauer, K., Private Communication.

4. Hepner, Thomas A., "TRANS-CONUS 86 VLF/LF Data Acquisition Project", CSC, San Diego, CA, September 30, 1987.

5. Hewlett Packard, "Operating Manual for Selective Level Meter HP3586A/B/C", 1979, Loveland, CO.

6. Hewlett Packard "HP-71 Owners Manual", February 1985, Hewlett Packard, Corvallis, OR.

7. McGrath, C.P., Private Communication.

8. Philco-Ford Corp., "Sierra 127C Frequency Selective Voltmeter Instruction Manual", Menlo Park, CA., October 1972, p1-2 & 1-3.

9. Watt, Arthur P., "VLF Radio Engineering", Glasgow, U.K., Pergamon Press, Inc., C. 1967 pp419-422.

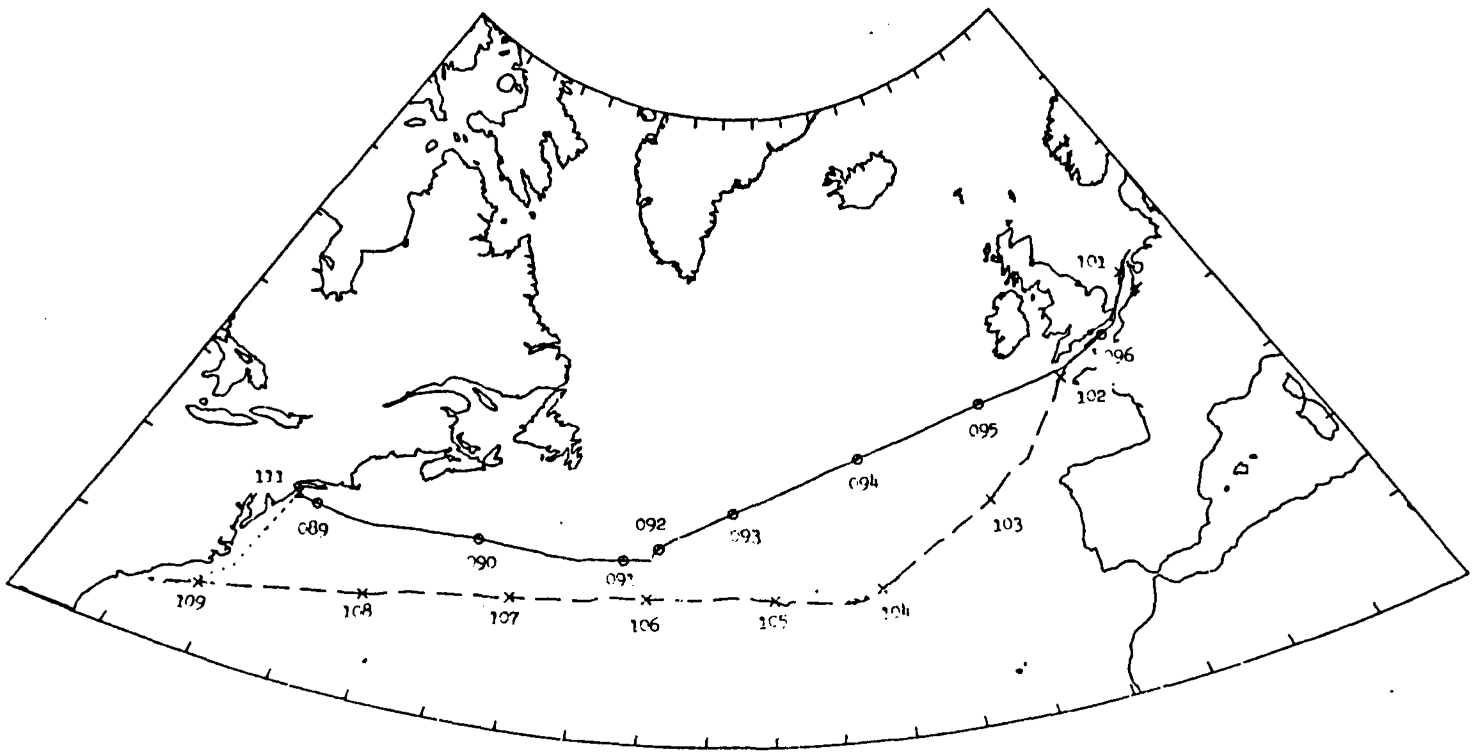
10. Maxwell, E.L, and Stone, D.L., "VLF Atmospheric Noise Predictions", DECO Electronics Inc., April 15, 1966.

APPENDIX A:
CALLAGHAN &
C-141
NAVIGATION
TRACTS

APPENDIX A

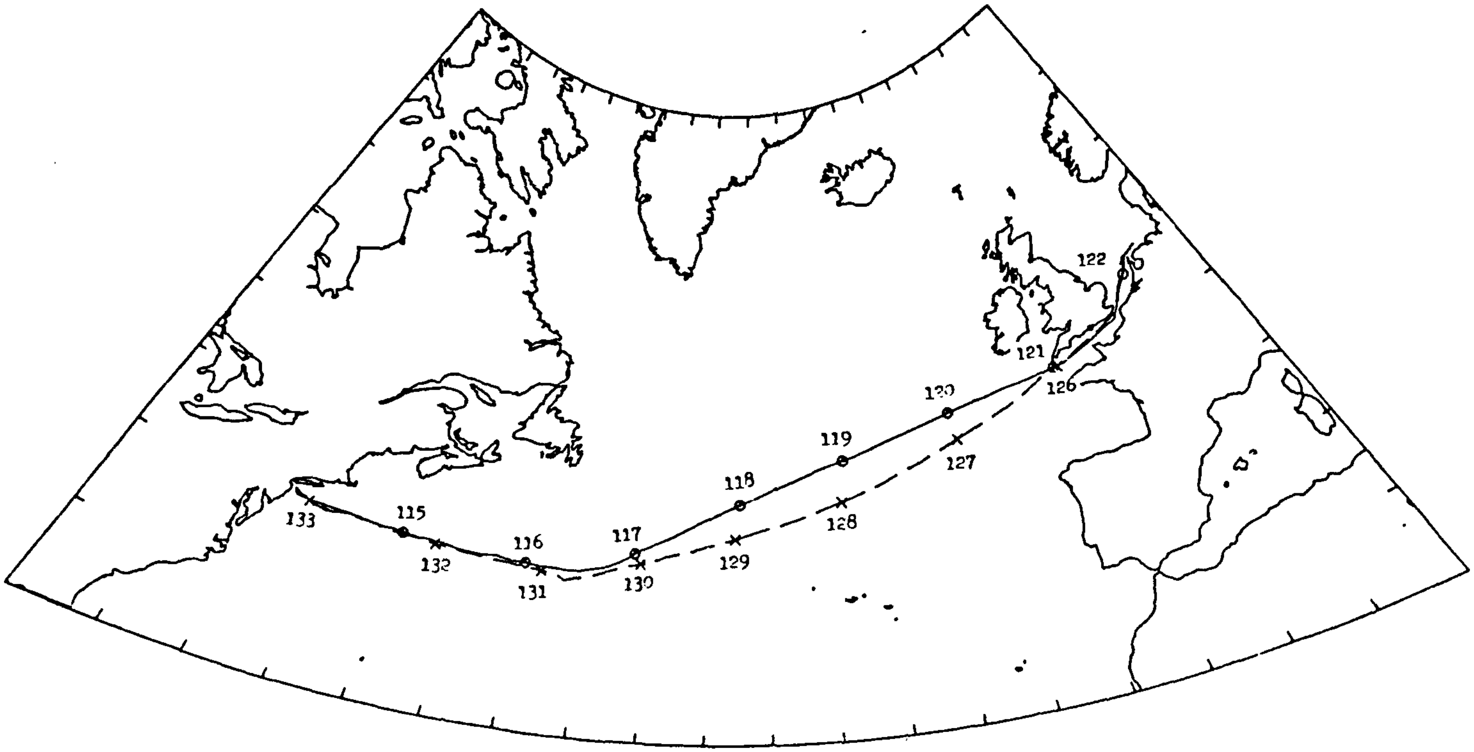
PAGE	FIGURE
1	GTS Callaghan trips 1 - 3.
2	GTS Callaghan trips 4 - 5.
3	GTS Callaghan trips 6 - 7.
4	GTS Callaghan trips 8 - 9.
5	GTS Callaghan trips 10 - 11.
6	GTS Callaghan trips 12 - 16.
7	GTS Callaghan trips 17 - 19.
8	GTS Callaghan trips 20 - 22.
9	GTS Callaghan trips 23 - 28.
10	GTS Callaghan trips 29 - 33.
11	GTS Callaghan trips 34 - 36.
12	GTS Callaghan trips 37 - 39.
13	GTS Callaghan trips 40 - 43.
14	GTS Callaghan trips 44 - 49.
15	GTS Callaghan trips 50 - 53.
16	June, 1984 NATL flights 1 - 2.
17	June, 1984 NATL flights 3 - 5.
18	June, 1984 NATL flights 6 - 8.
19	June, 1984 NATL flights 9 - 12.
20	June, 1984 NATL flights 13 - 17.
21	February, 1985 NATL flights 1 - 3.
22	February, 1985 NATL flights 4 - 6.
23	February, 1985 NATL flights 7 - 10.
24	February, 1985 NATL flights 11 - 15.
25	February, 1985 NATL flights 16 - 19.
26	February, 1985 NATL flights 20 - 21.
27	September, 1985 NATL flights 1 - 3.
28	September, 1985 NATL flights 4 - 8.

GTS CALLAGHAN, TRIP 1 BAYONNE TO BREMMERHAVEN DAY 85088 TO 85096	(03-29-85) TO (04-06-85)
GTS CALLAGHAN, TRIP 2 BREMMERHAVEN TO CHARLESTON DAY 85100 TO 85109	(04-11-85) TO (04-19-85)
GTS CALLAGHAN, TRIP 3 CHARLESTON TO BAYONNE DAY 85110 TO 85111	(04-20-85) TO (04-21-85)

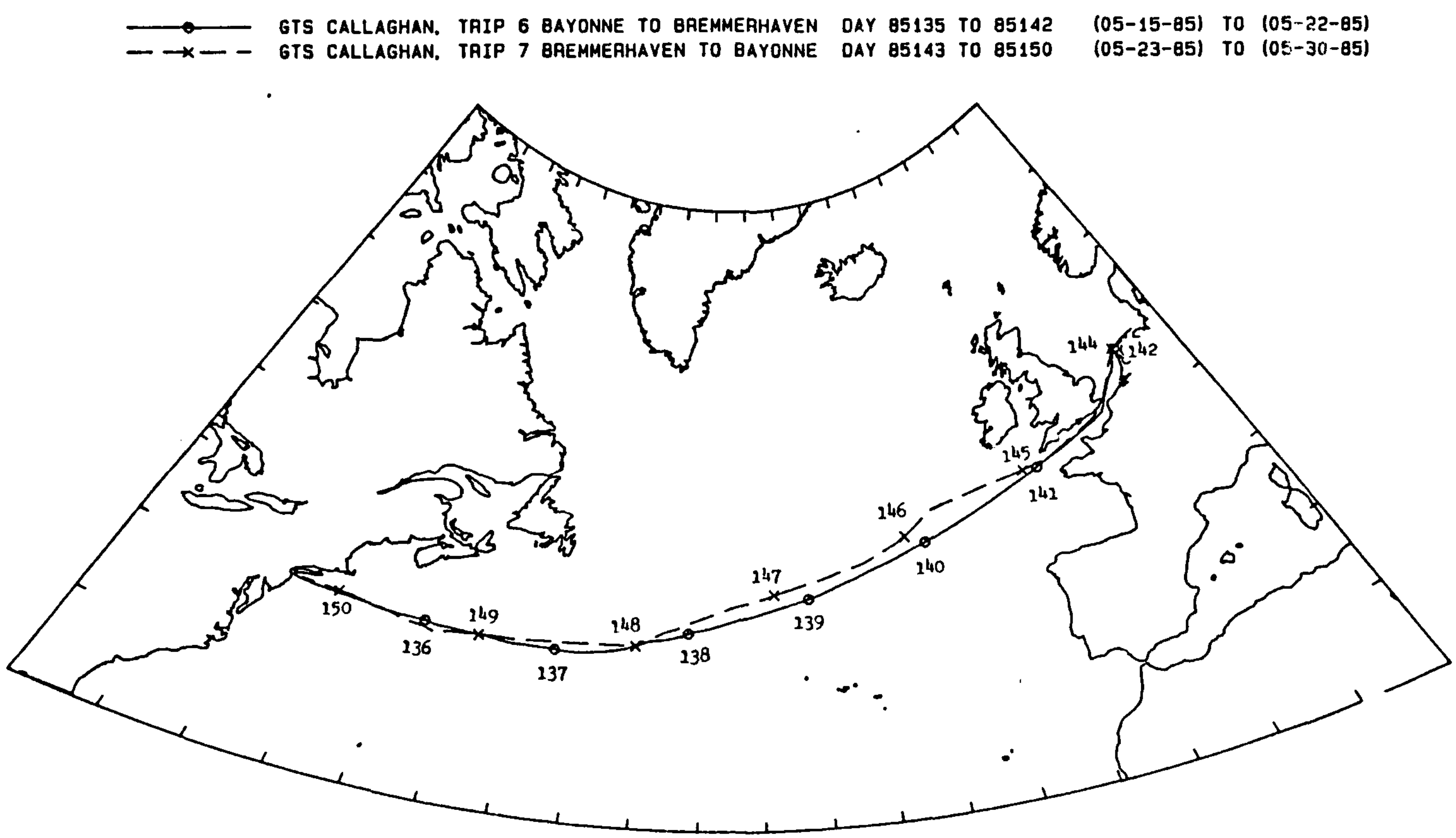


Coordinates are (85. 30.) (-10. 70.) (999.0 99.0)

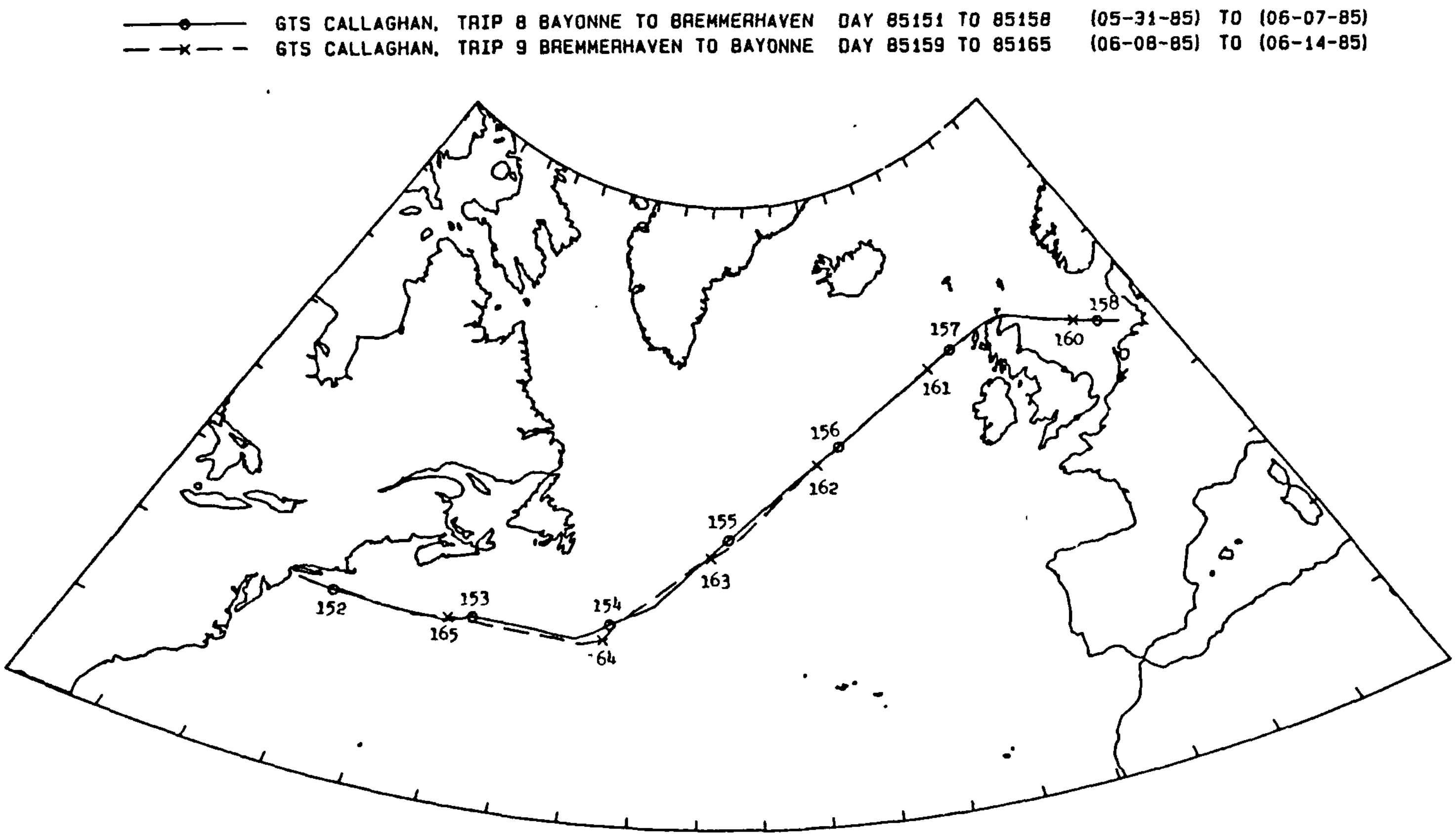
GTS CALLAGHAN, TRIP 4 BAYONNE TO BREMMERHAVEN DAY 85114 TO 85122 (04-24-85) TO (05-02-85)
GTS CALLAGHAN, TRIP 5 BREMMERHAVEN TO BAYONNE DAY 85125 TO 85133 (05-05-85) TO (05-13-85)



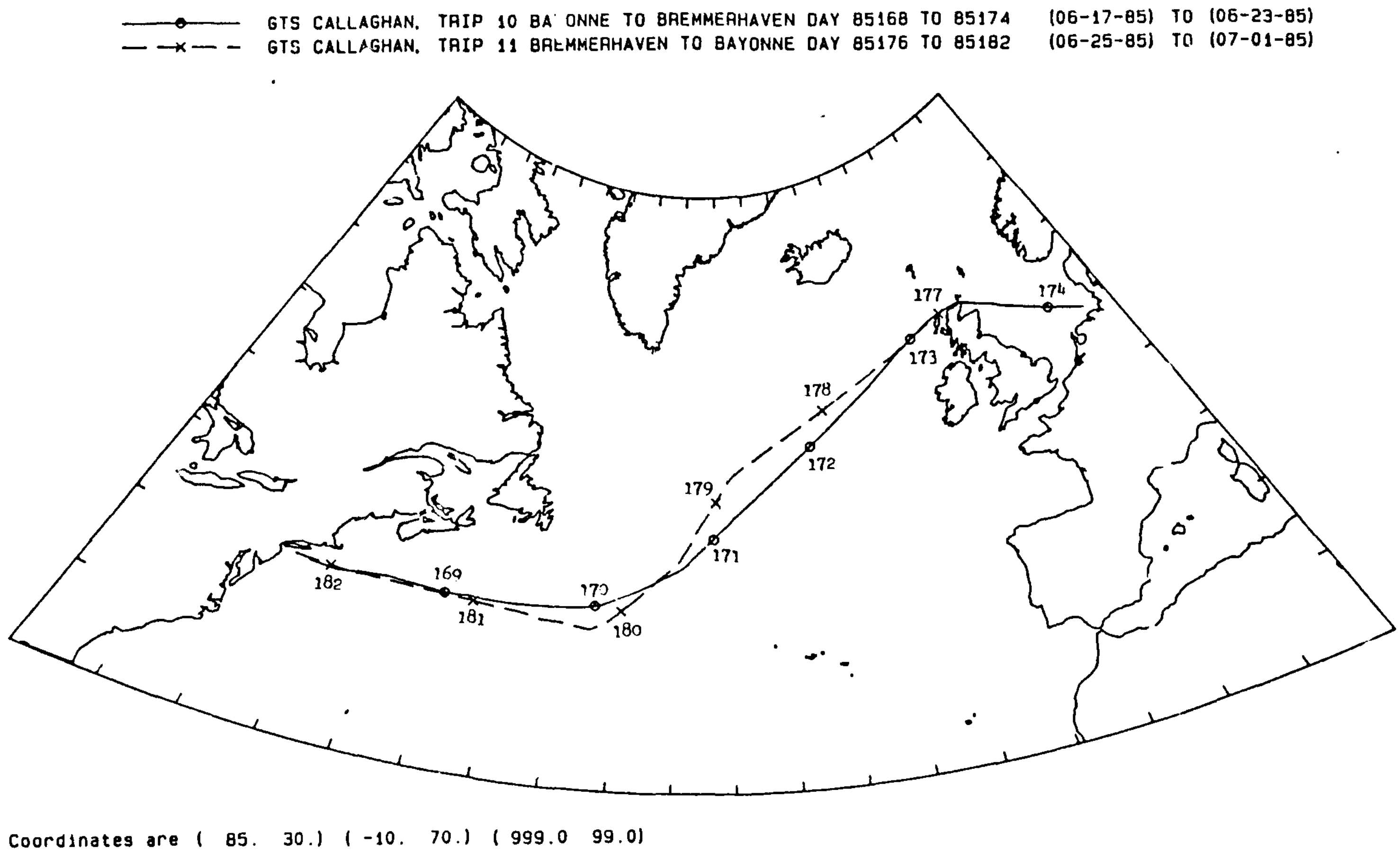
Coordinates are (85. 30.) (-10. 70.) (999.0 99.0)



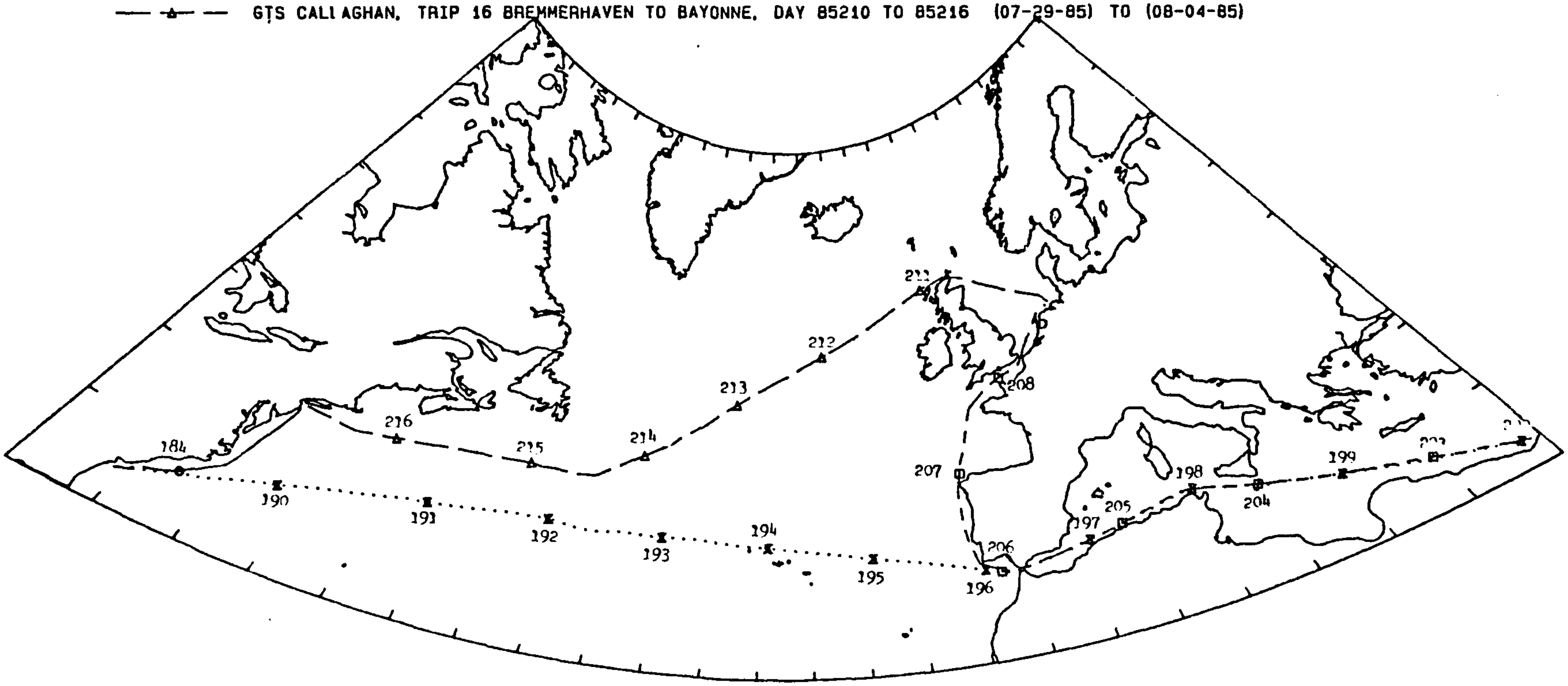
Coordinates are (85. 30.) (-10. 70.) (999.0 99.0)



Coordinates are (85. 30.) (-10. 70.) (999.0 99.0)


GTS CALLAGHAN, TRIP 10 BA ONNE TO BREMMERHAVEN DAY 85168 TO 85174 (06-17-85) TO (06-23-85)
GTS CALLAGHAN, TRIP 11 BREMMERHAVEN TO BAYONNE DAY 85176 TO 85182 (06-25-85) TO (07-01-85)
169
170
171
172
173
174
177
178
179
180
181
182
Coordinates are (85. 30.) (-10. 70.) (999.0 99.0)

GTS CALLAGHAN, TRIP 12 BAYONNE TO CHARLESTON DAY 85183 TO 85184 (07-02-85) TO (07-03-85)
GTS CALLAGHAN, TRIP 13 CHARLESTON TO SAVANNAH DAY 85185 TO 85185 (07-04-85) TO (07-04-85)
GTS CALLAGHAN, TRIP 14 SAVANNAH TO ALEXANDRIA DAY 85189 TO 85200 (07-08-85) TO (07-19-85)
GTS CALLAGHAN, TRIP 15 ALEXANDRIA TO BREMMERHAVEN DAY 85202 TO 85208 (07-21-85) TO (07-27-85)
GTS CALLAGHAN, TRIP 16 BREMMERHAVEN TO BAYONNE, DAY 85210 TO 85216 (07-29-85) TO (08-04-85)



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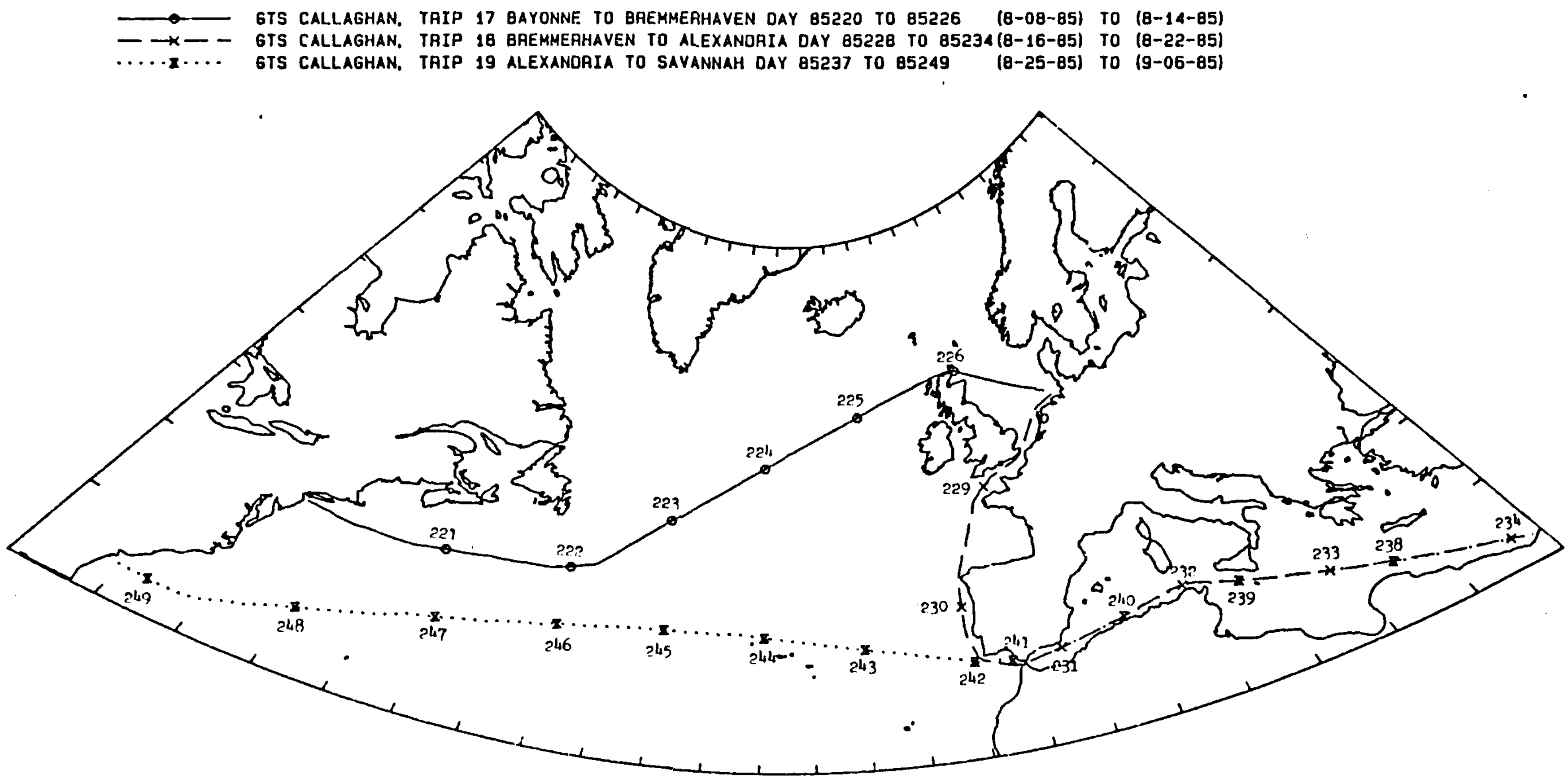

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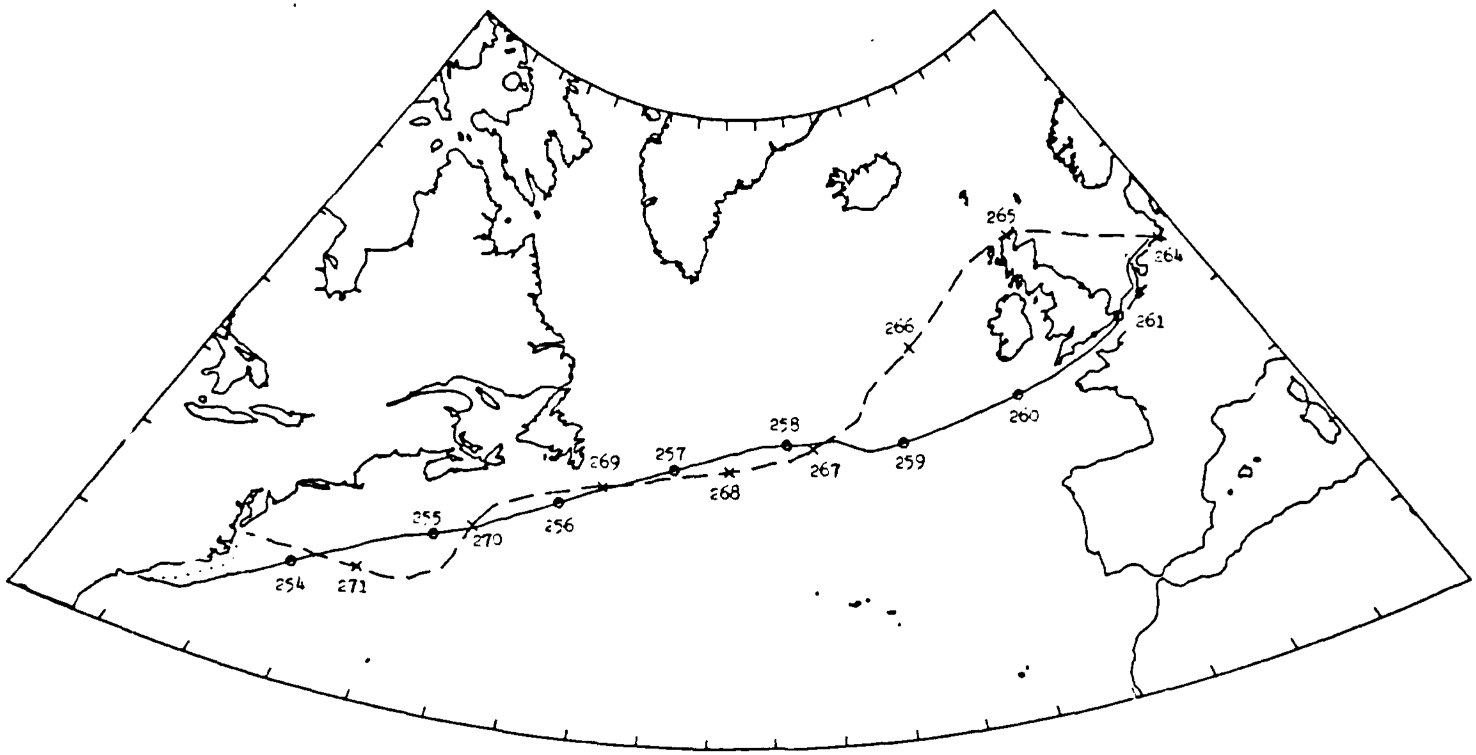
GTS CALLAGHAN, TRIP 20 SAVANNAH TO BREMMERHAVEN DAY 85253 TO 85261 (9-10-85) TO (9-18-85)
GTS CALLAGHAN, TRIP 21 BREMMERHAVEN TO NORFOLK DAY 85263 TO 85271 (9-20-85) TO (9-28-85)
GTS CALLAGHAN, TRIP 22 NORFOLK TO CHARLESTON DAY 85273 TO 85273 (9-30-85) TO (9-30-85)



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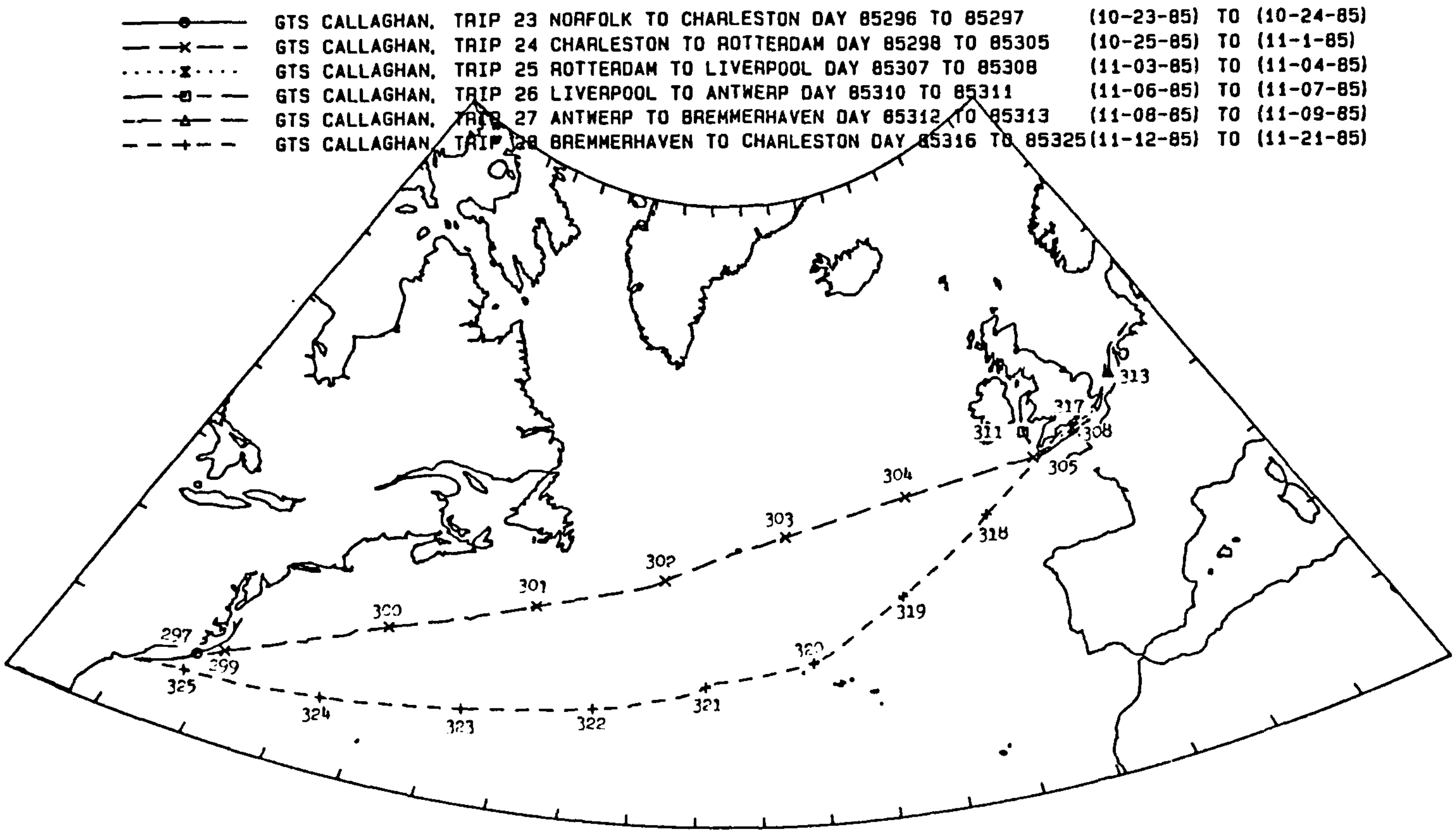

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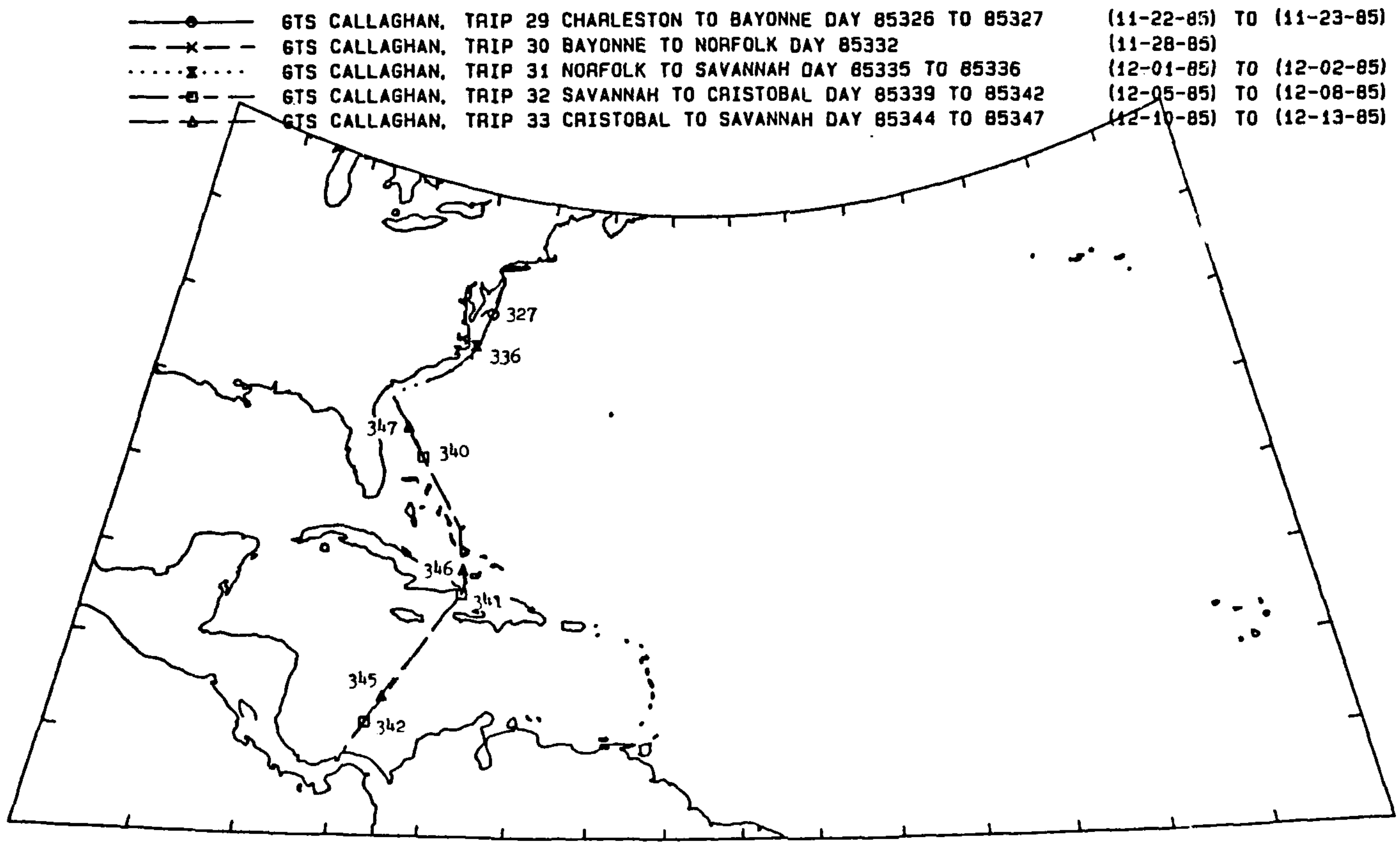
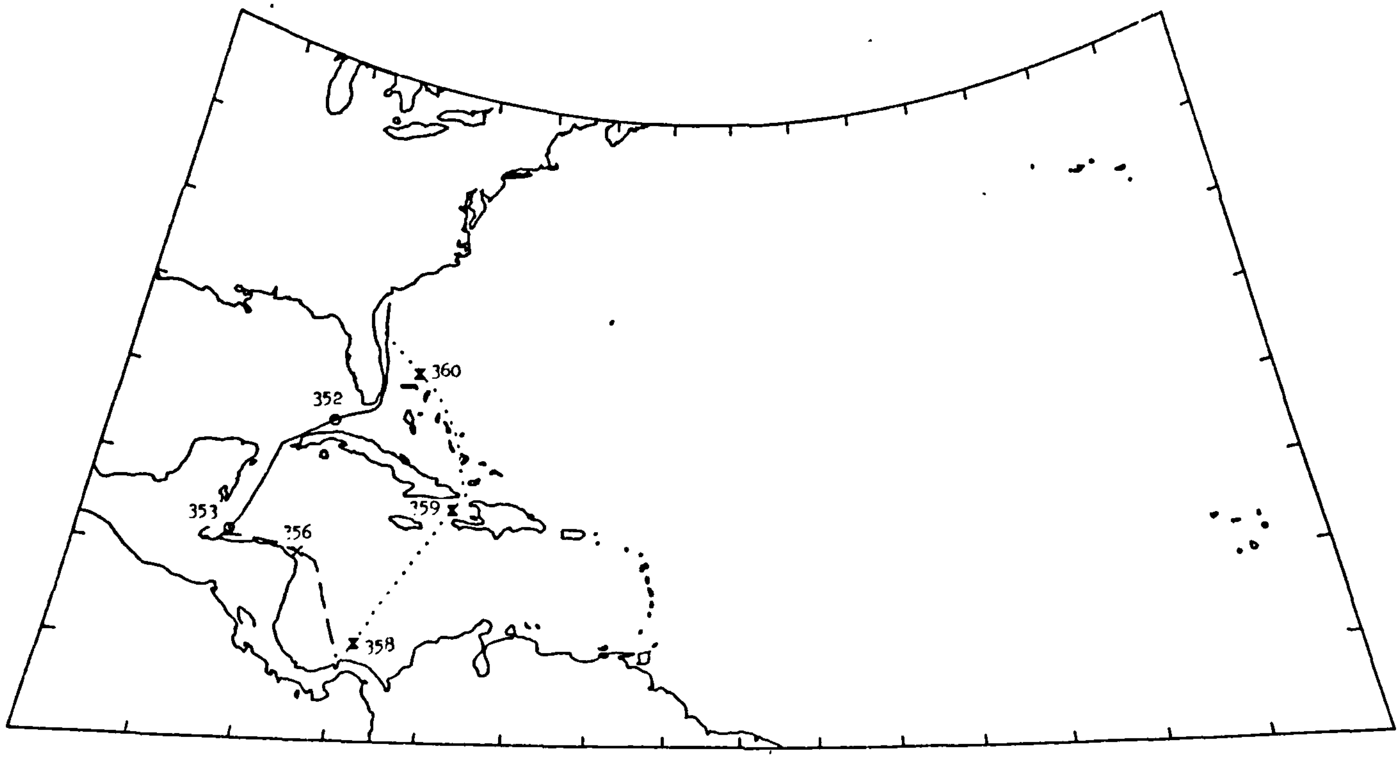
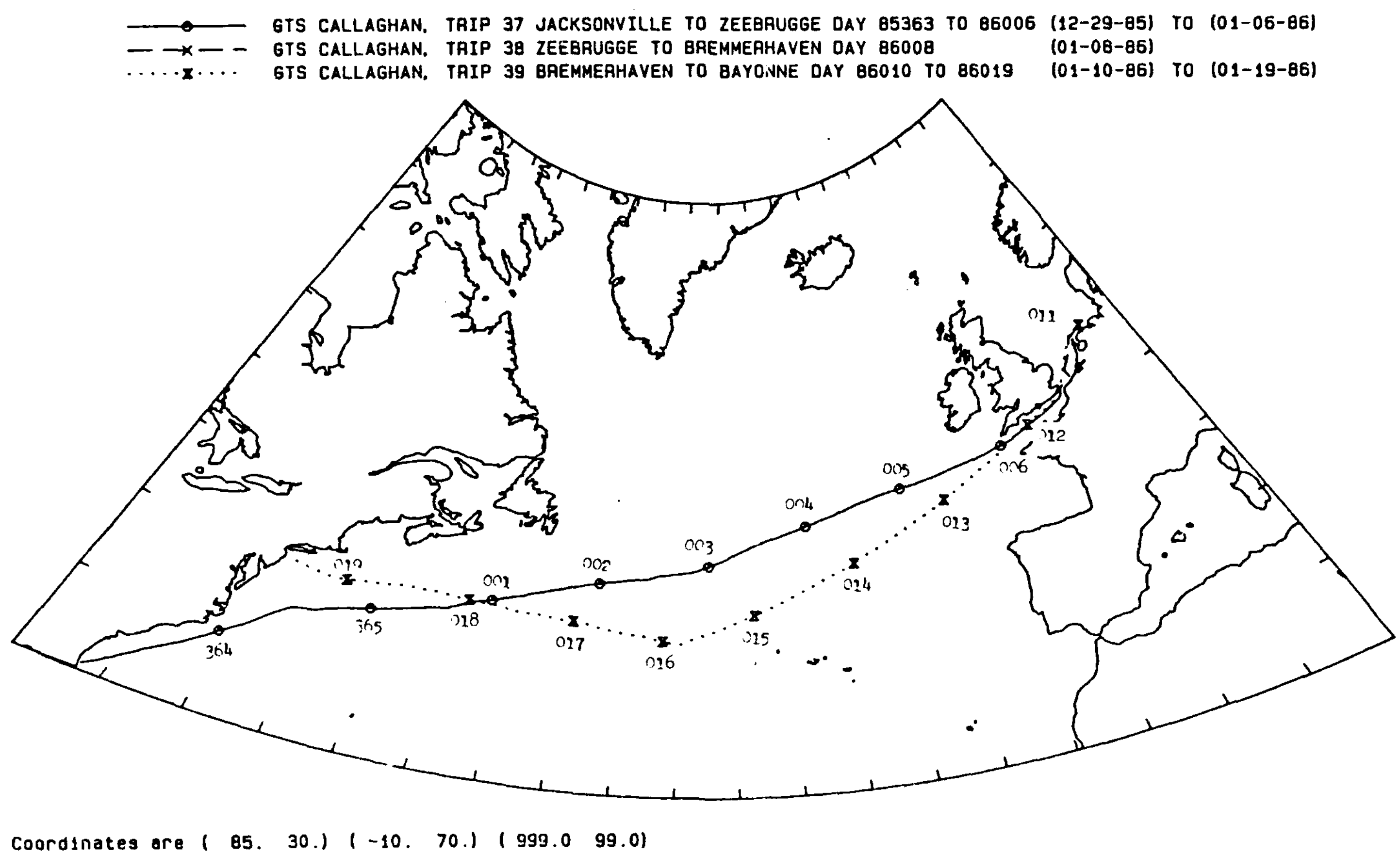


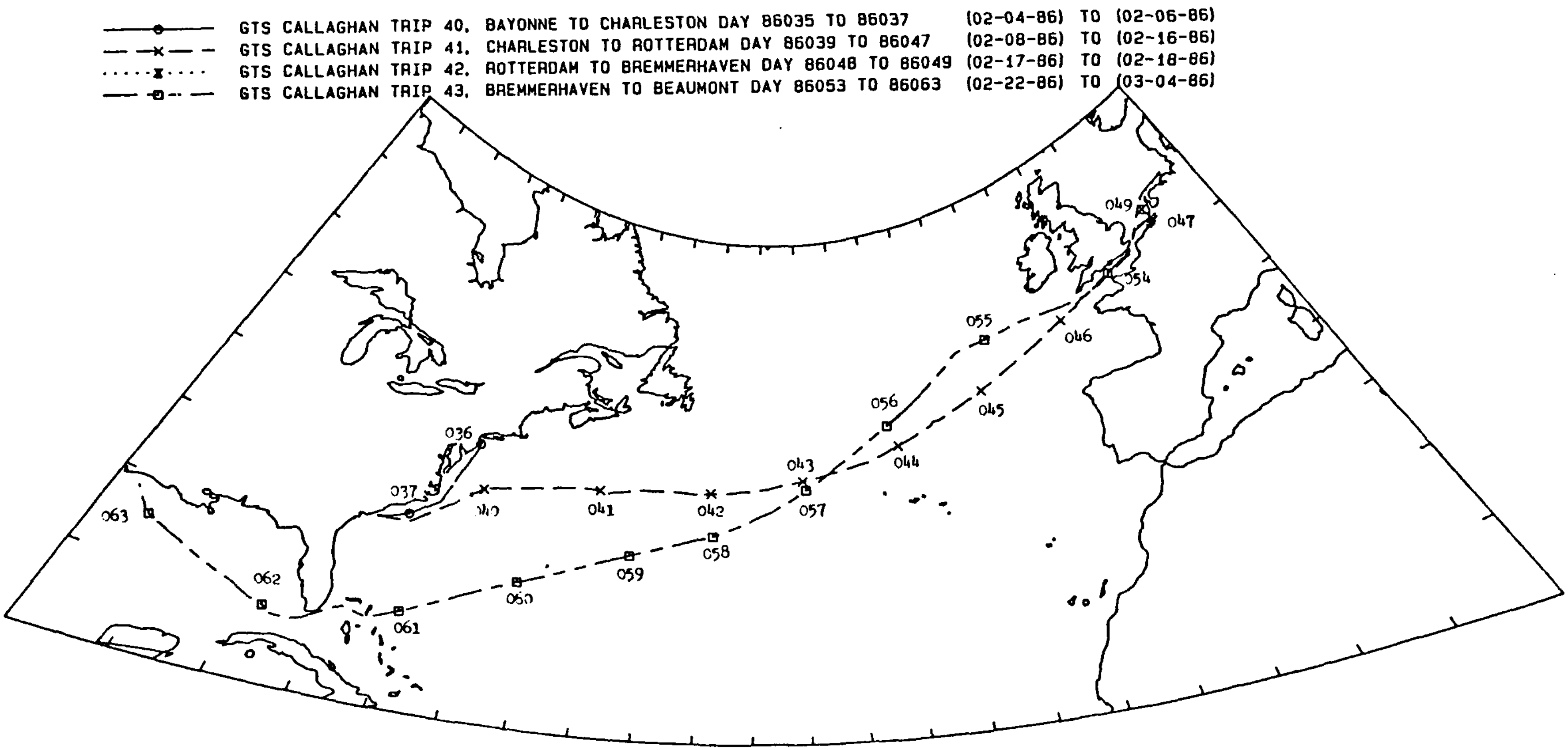
Coordinates are (95. 5.) (20. 45.) (999.0 99.0)

GTS CALLAGHAN, TRIP 34 SAVANNAH TO PUERTO CORTEZ DAY 85351 TO 85353 (12-17-85) TO (12-19-85)
GTS CALLAGHAN, TRIP 35 PUERTO CORTEZ TO CRISTOBAL DAY 85355 TO 85356(12-21-85) TO (12-22-85)
GTS CALLAGHAN, TRIP 36 CRISTOBAL TO JACKSONVILLE DAY 85357 TO 85360 (12-23-85) TO (12-26-85)



Coordinates are (95. 5.) (20. 45.) (999.0 99.0)


GTS CALLAGHAN, TRIP 37 JACKSONVILLE TO ZEEBRUGGE DAY 85363 TO 86006 (12-29-85) TO (01-06-86)
GTS CALLAGHAN, TRIP 38 ZEEBRUGGE TO BREMMERHAVEN DAY 86008 (01-08-86)
GTS CALLAGHAN, TRIP 39 BREMMERHAVEN TO BAYONNE DAY 86010 TO 86019 (01-10-86) TO (01-19-86)
011
012
006
005
004
003
002
001
013
014
015
016
017
018
365
364
019
Coordinates are (85. 30.) (-10. 70.) (999.0 99.0)



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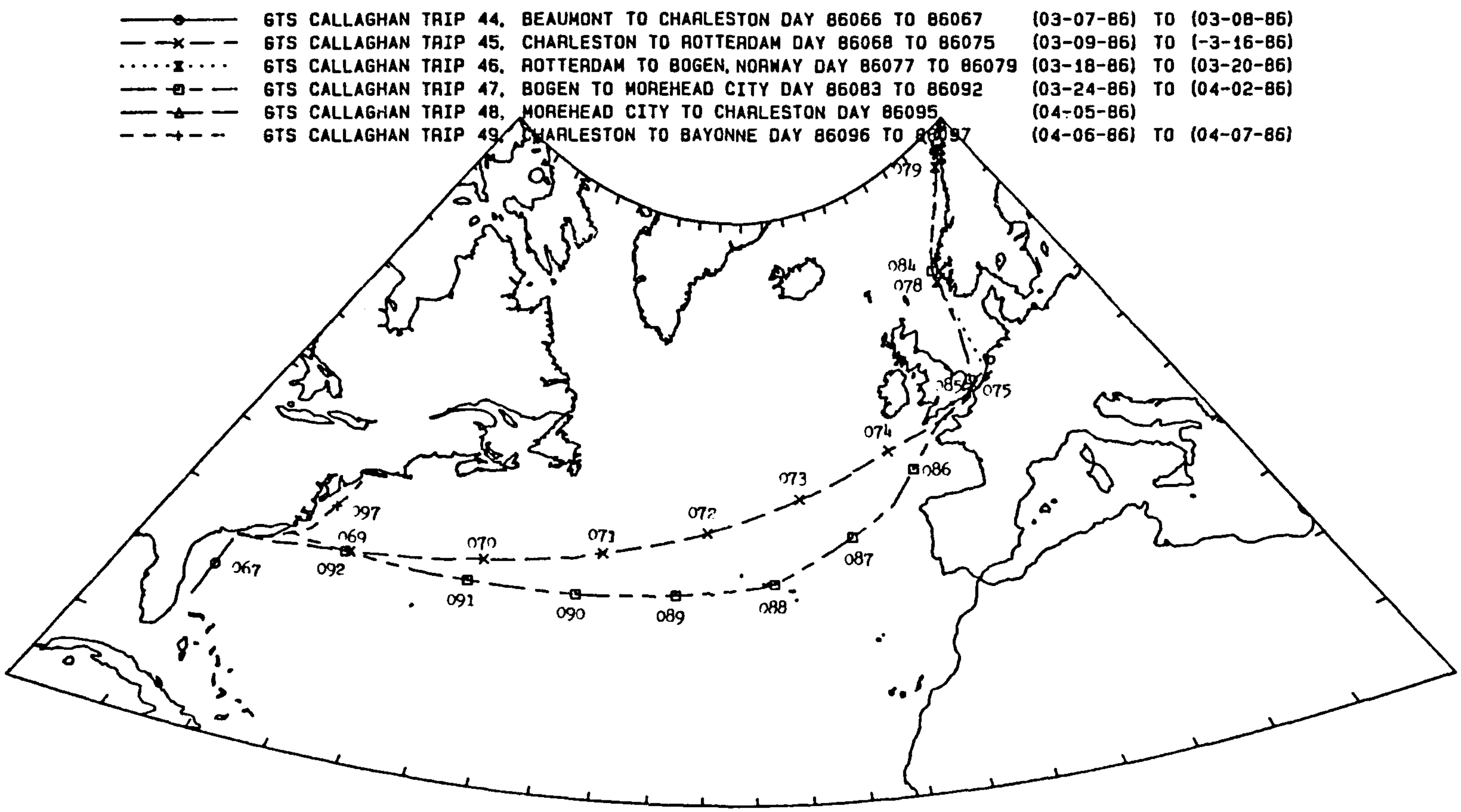

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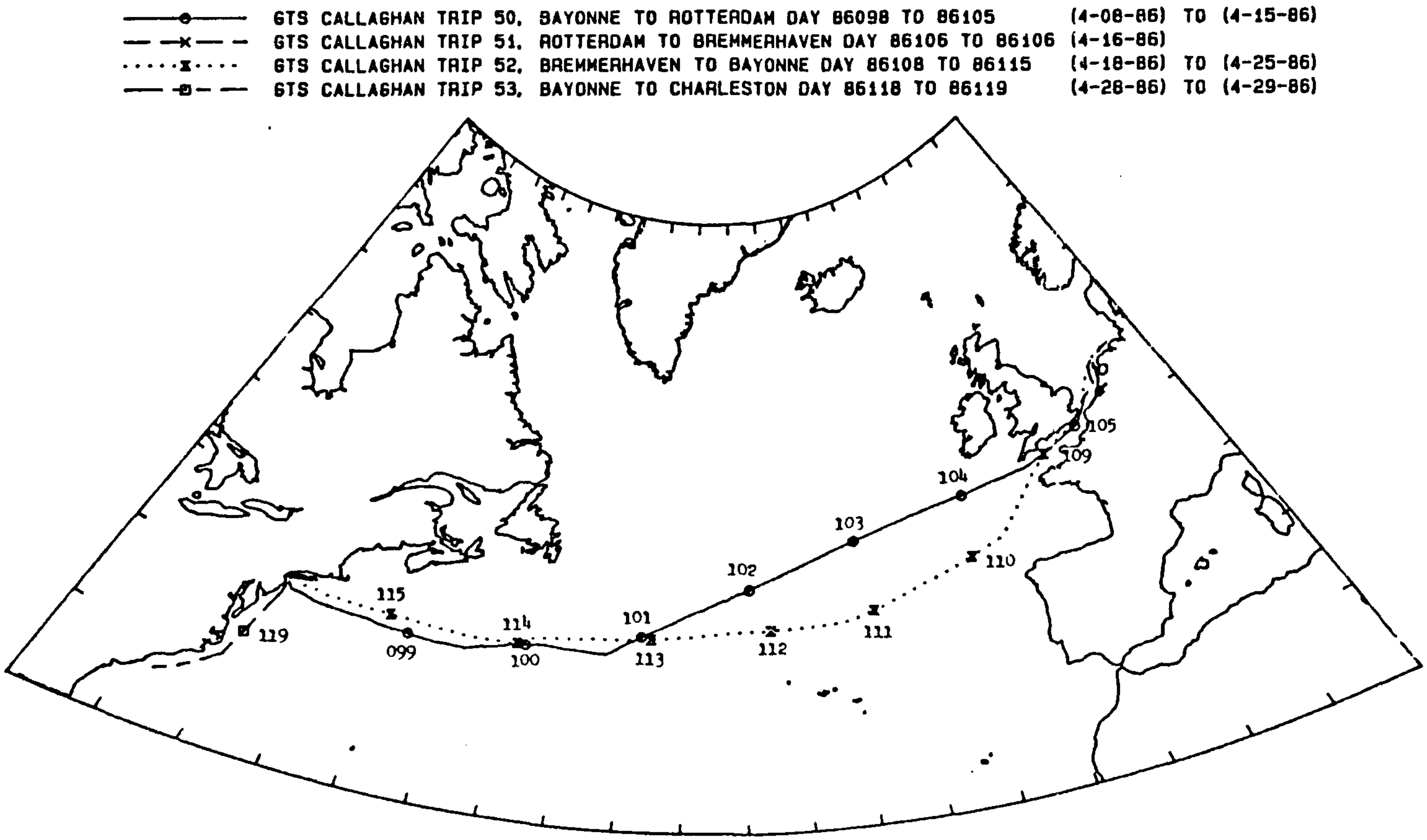

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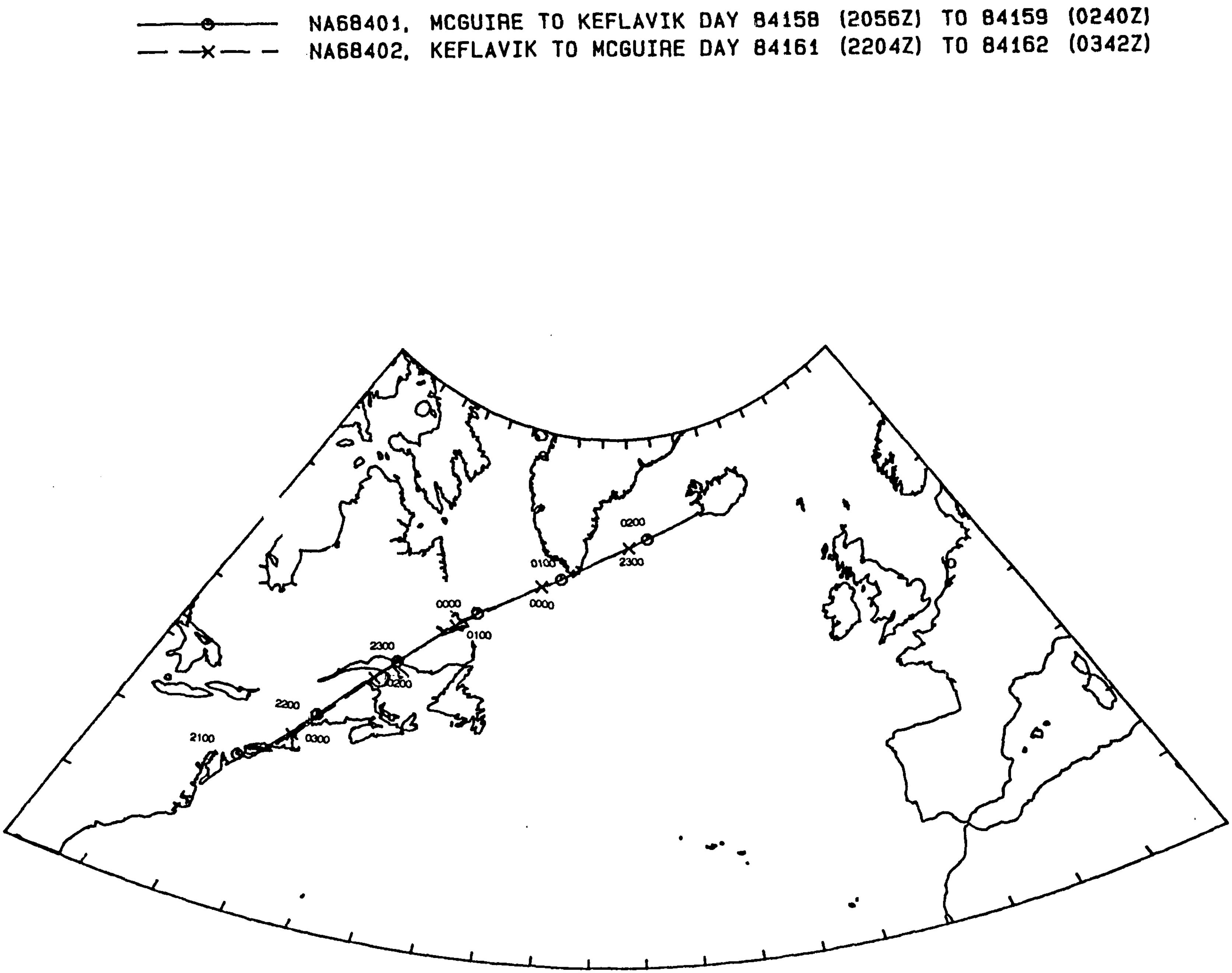
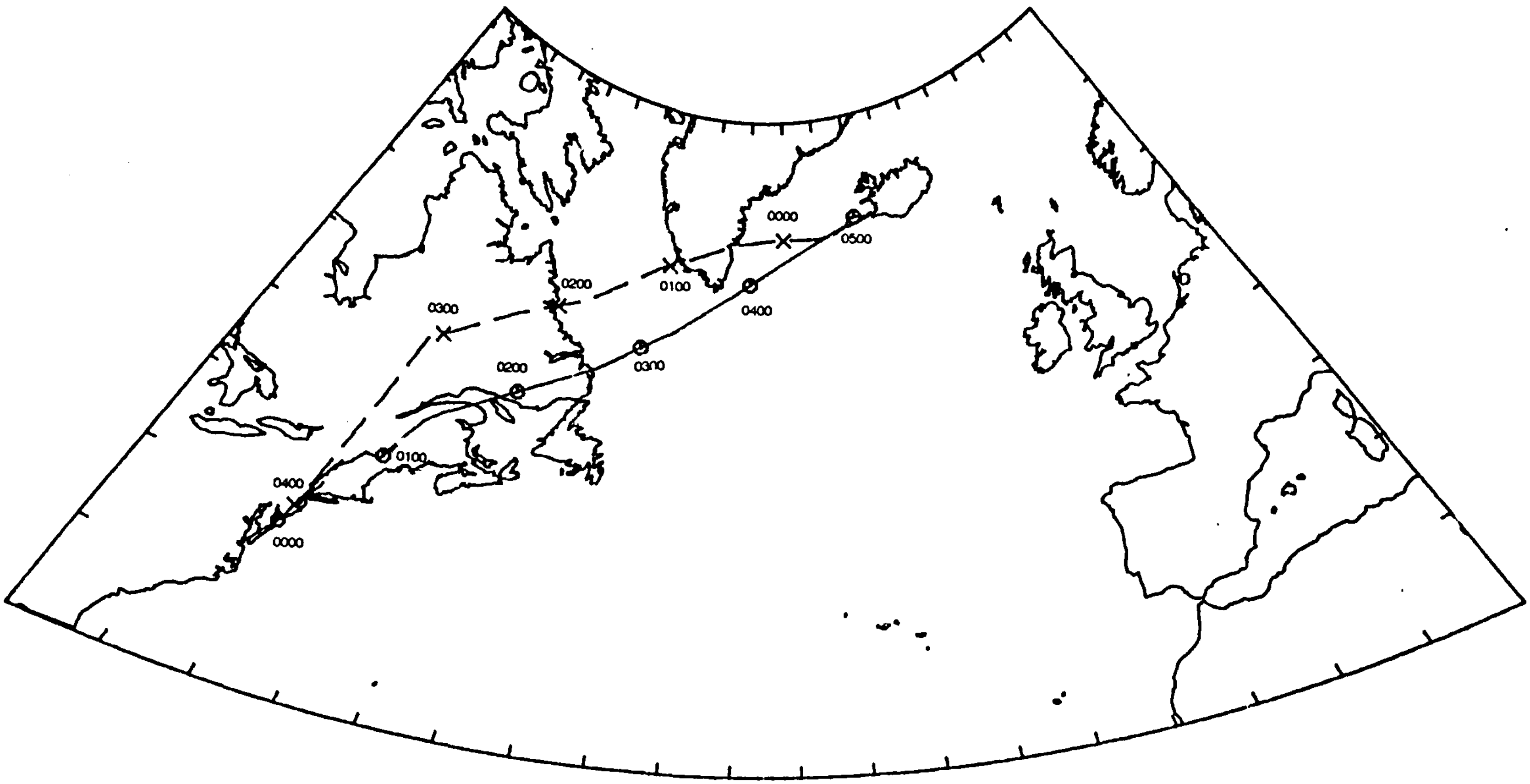


Coordinates are (85. 30.) (-10. 70.) (999.0 99.0)

NA68403, NORFOLK TO KEFLAVIK DAY 84165 (2?35Z) TO 84166 (0517Z)
NA68404, KEFLAVIC TO MCGUIRE DAY 84166 (2304Z) TO 84167 (0459Z)
NA68405, MCGUIRE TO NORFOLK 84167 (1914Z) TO (1956Z)



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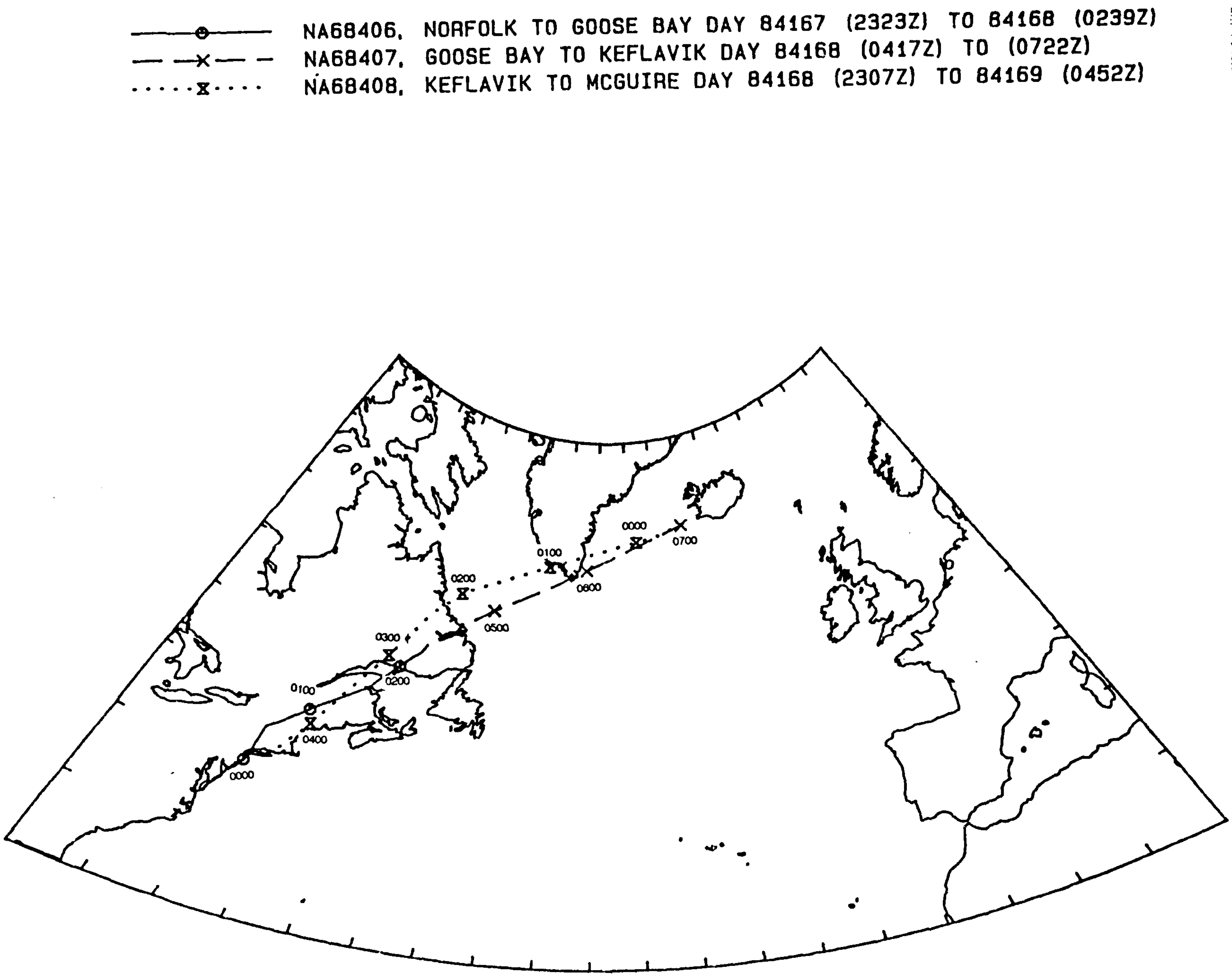

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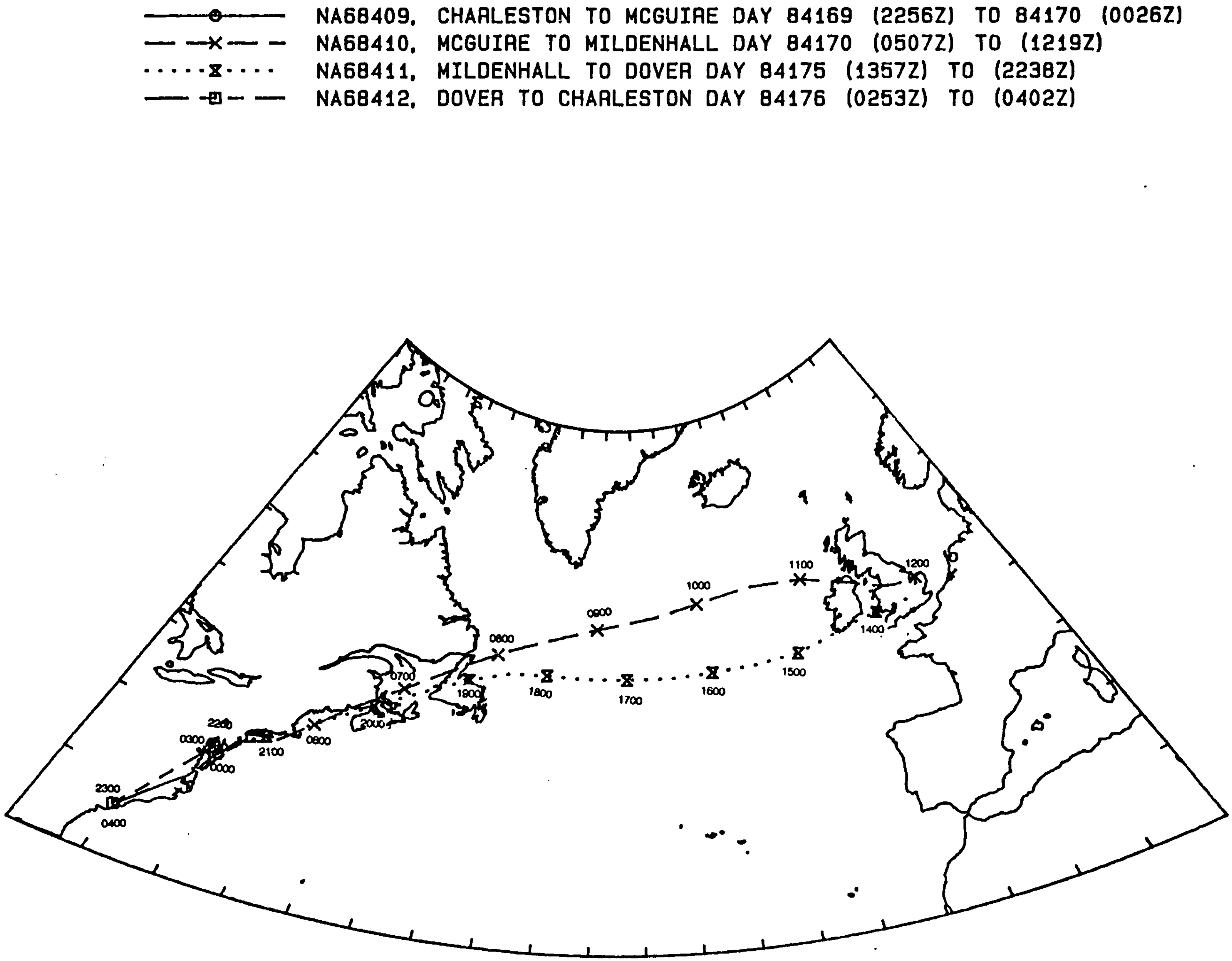

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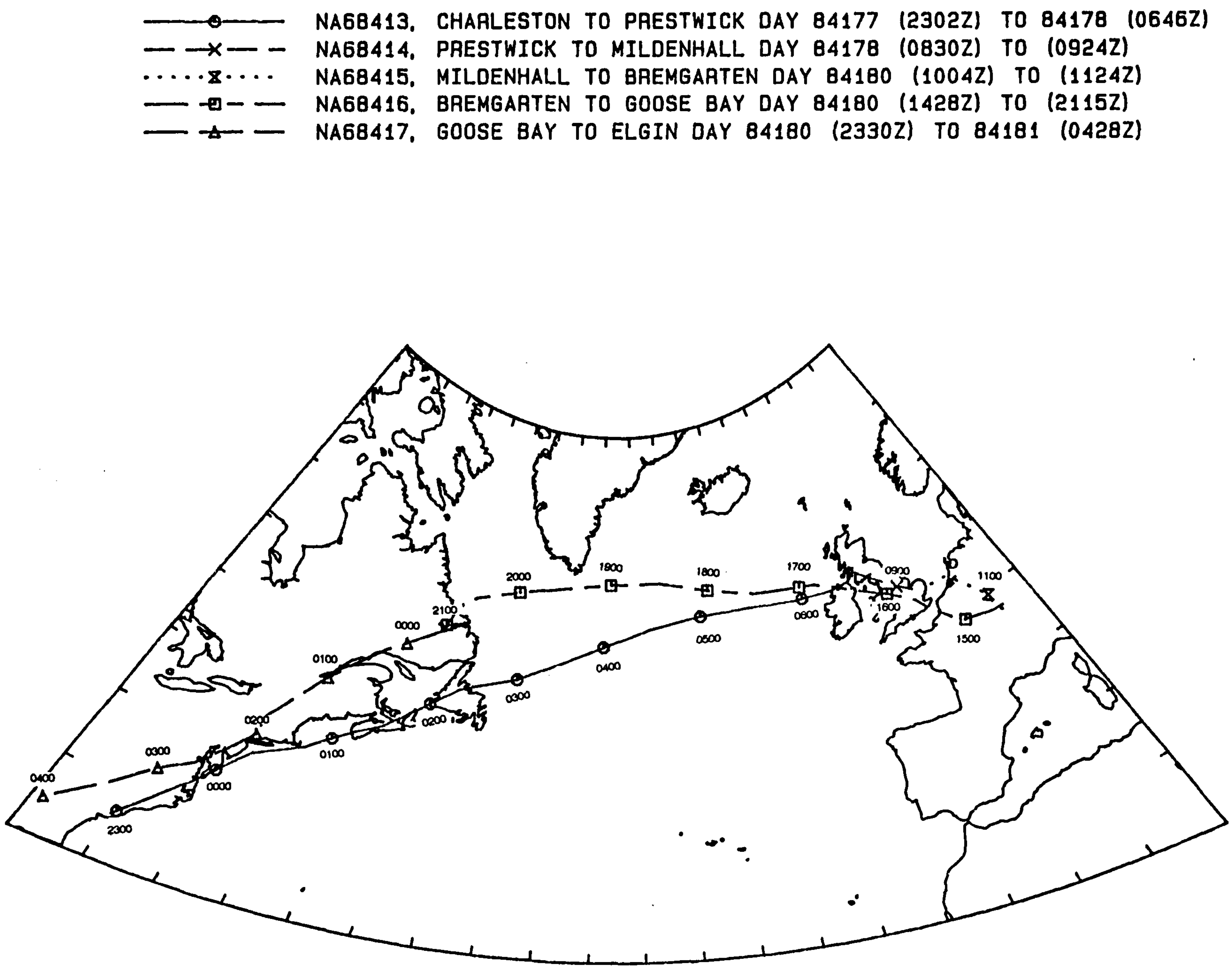
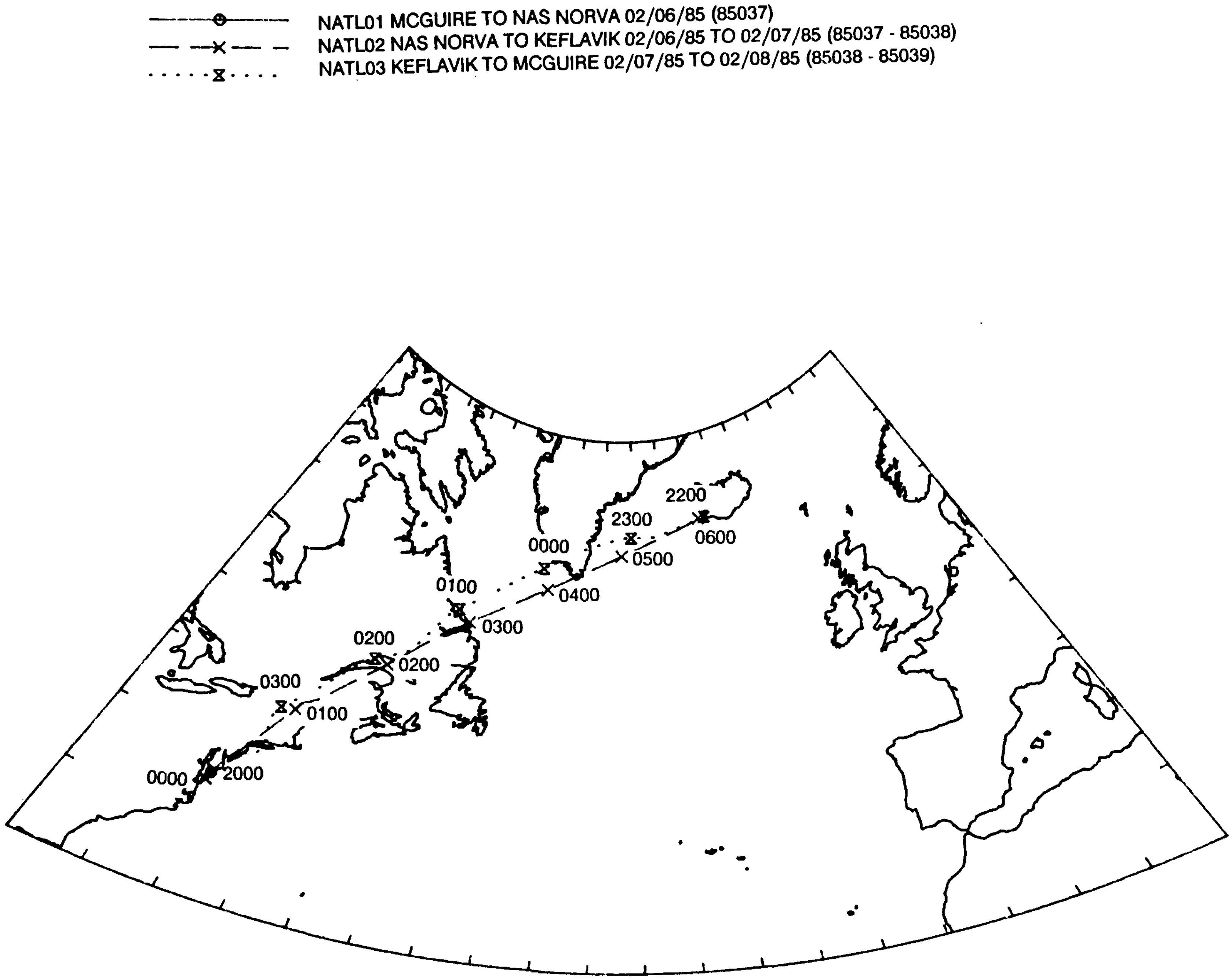
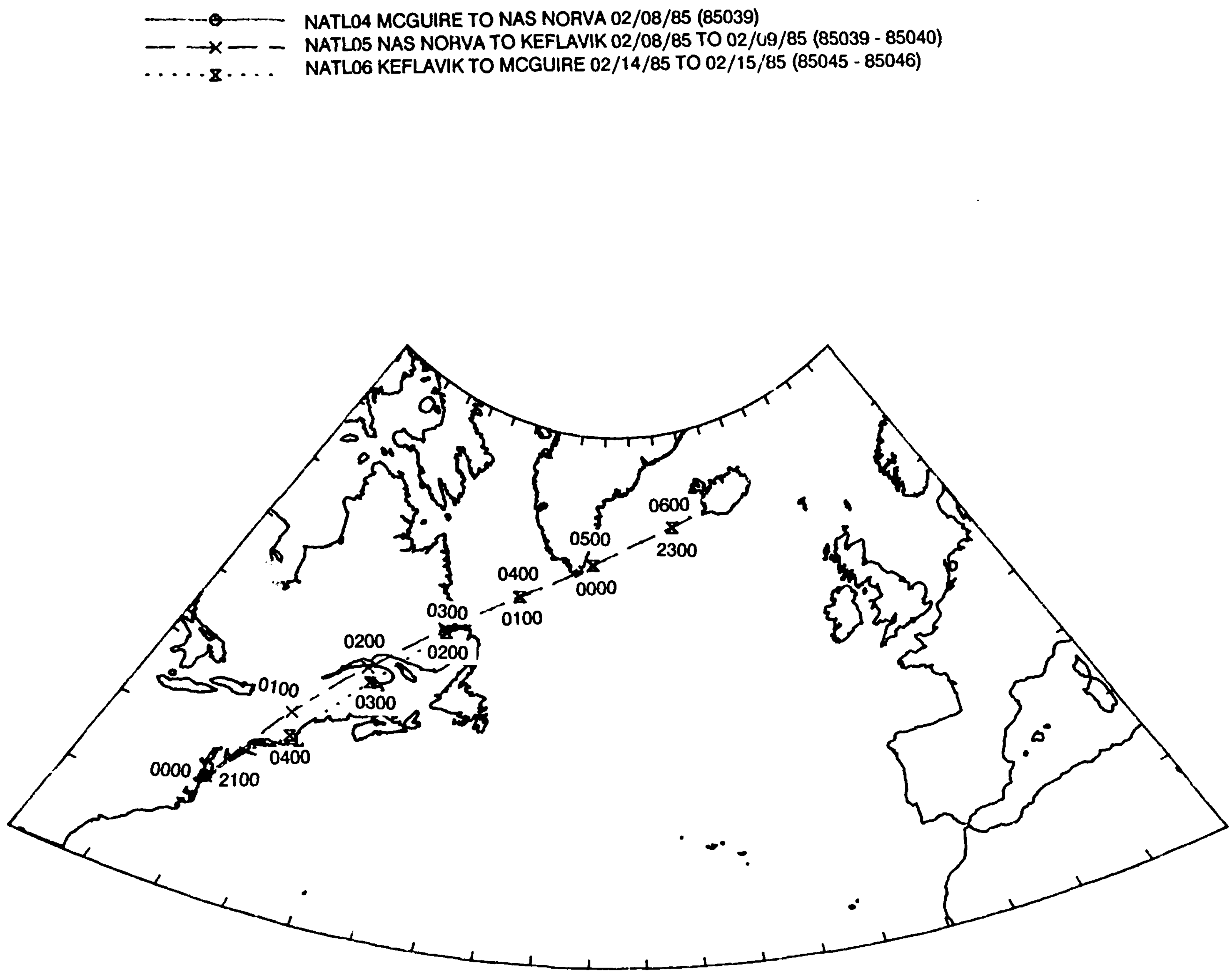


Coordinates are (85. 30.) (-10. 70.) (999.0 99.0)



Coordinates are (85. 30.) (-10. 70.) (999.0 99.0)



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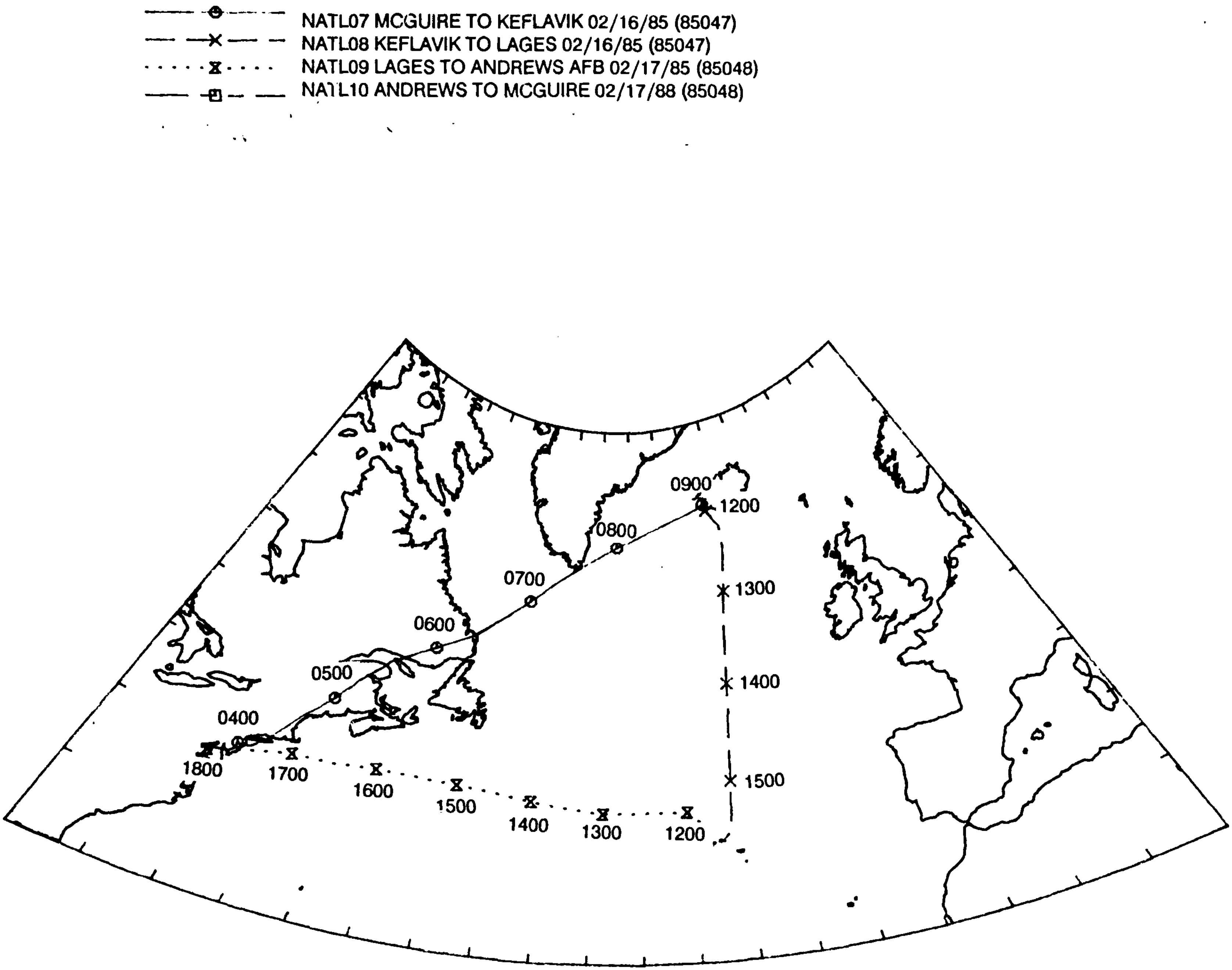
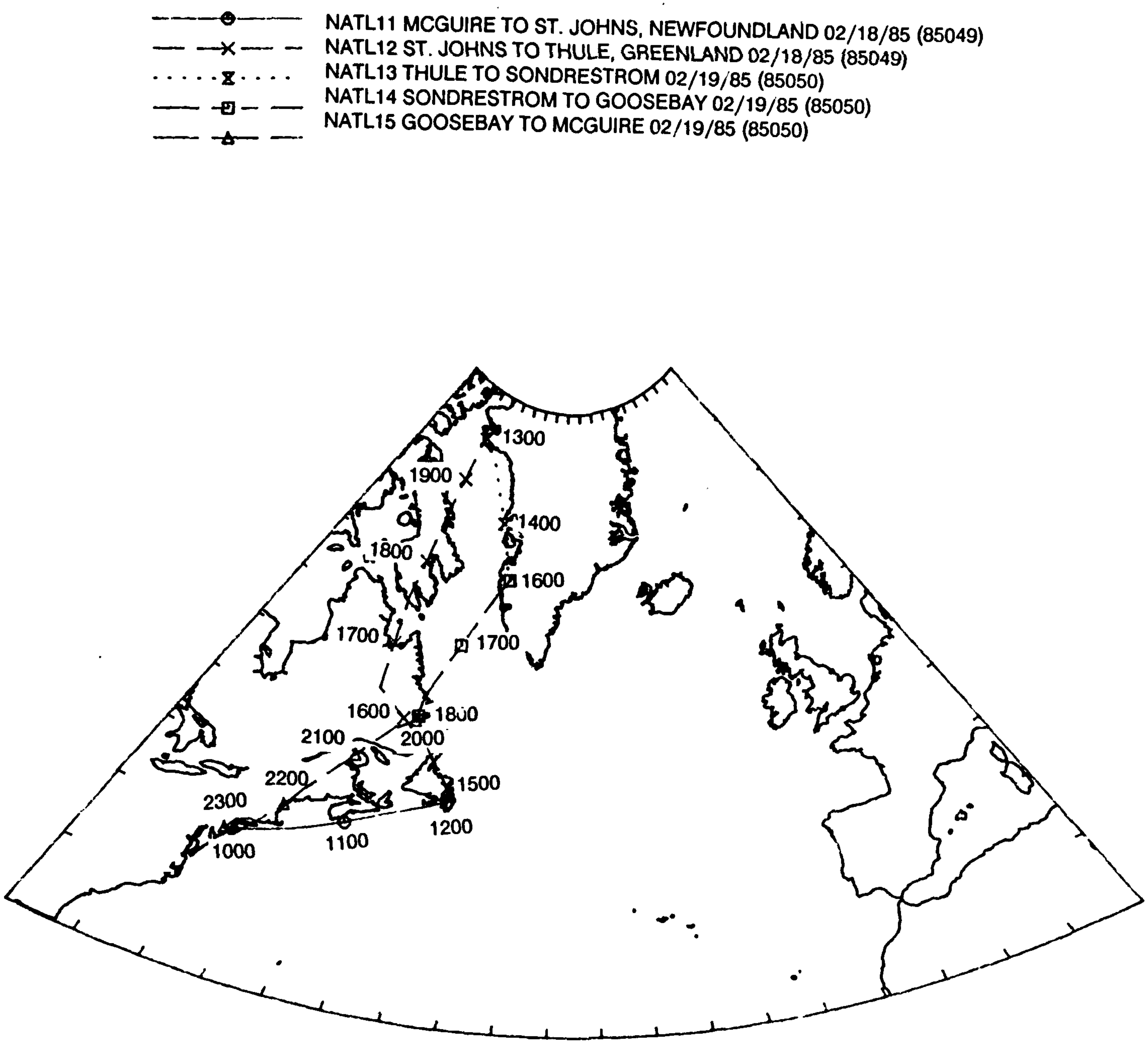
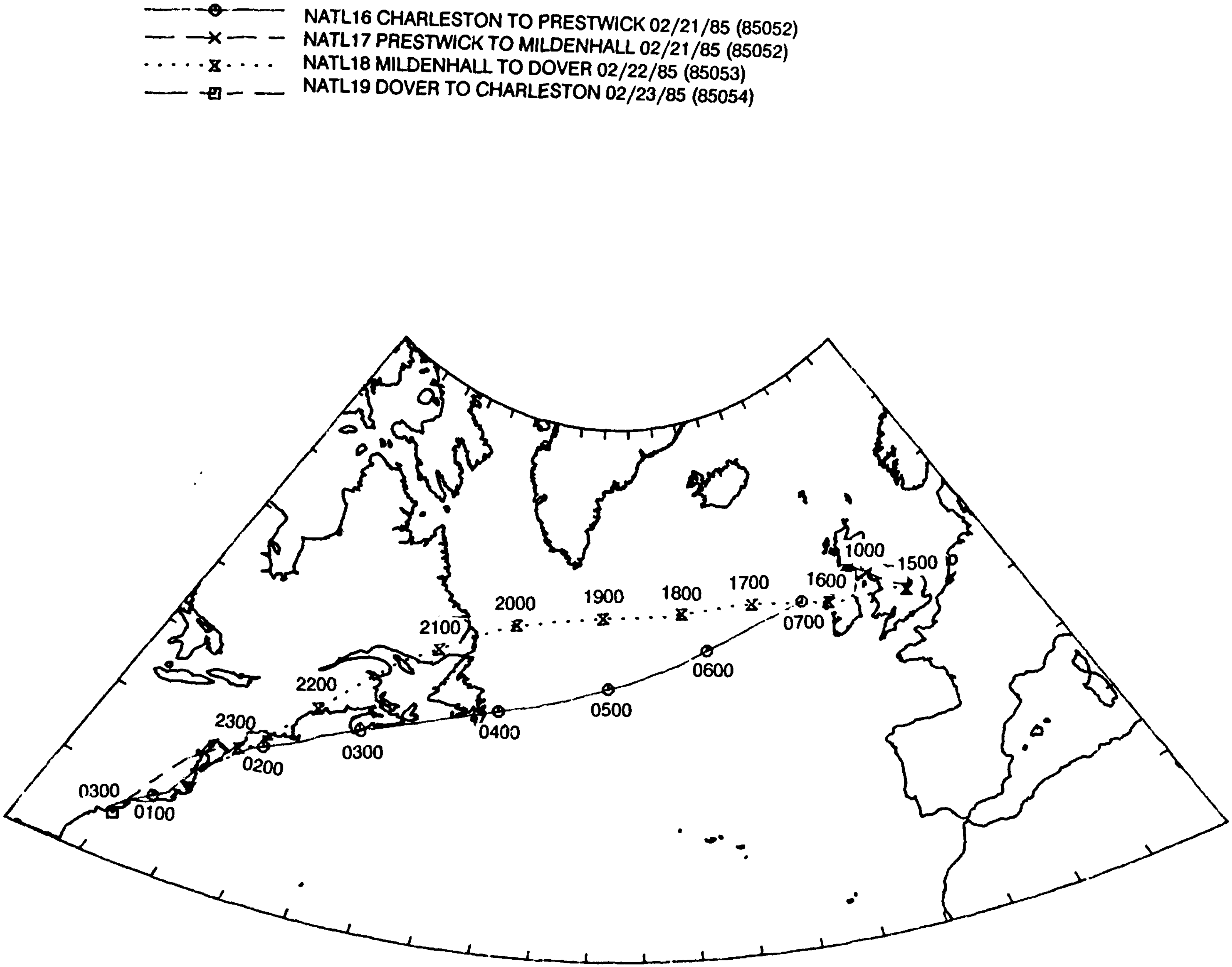


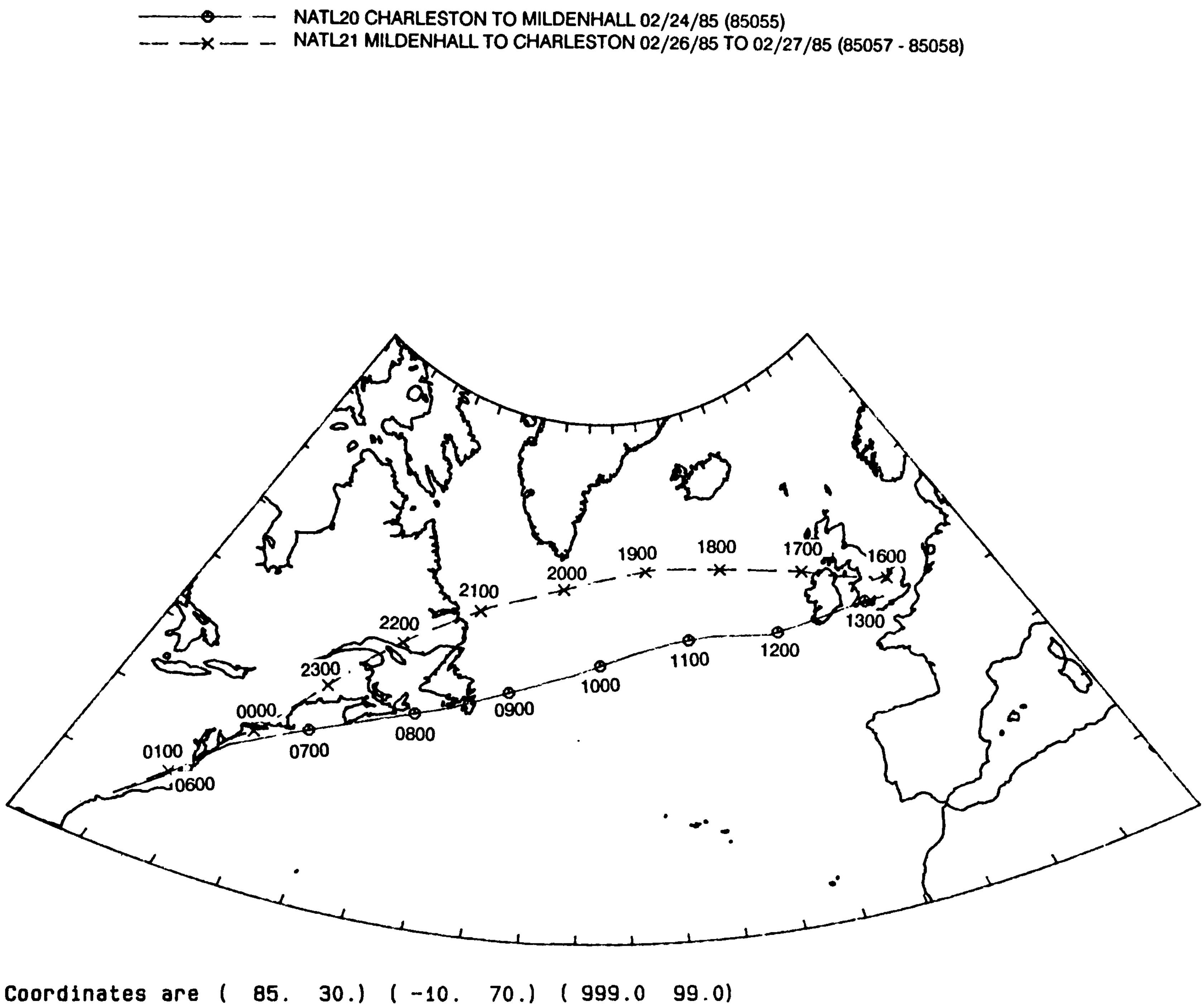
Coordinates are (85. 30.) (-10. 70.) (999.0 99.0)



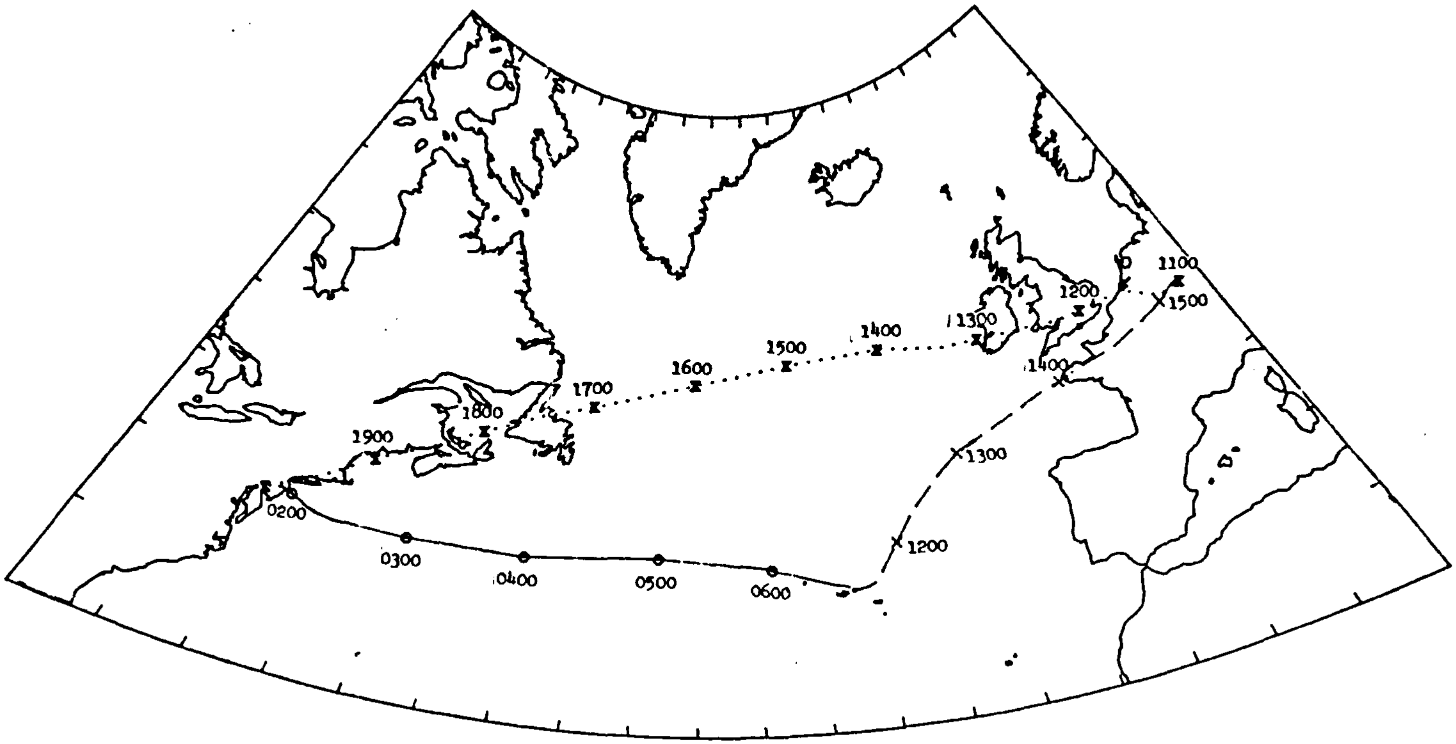
Coordinates are (85. 30.) (-10. 80.) (999.0 99.0)



Coordinates are (85. 30.) (-10. 70.) (999.0 99.0)


NATL20 CHARLESTON TO MILDENHALL 02/24/85 (85055)
NATL21 MILDENHALL TO CHARLESTON 02/26/85 TO 02/27/85 (85057 - 85058)
0100
0600
0000
0700
2300
0800
2200
0900
2100
1000
2000
1100
1900
1800
1200
1700
1300
1600
Coordinates are (85. 30.) (-10. 70.) (999.0 99.0)

——o——	NA98501, MCGUIRE TO LAGES, DAY 260 (0148Z) TO (0644Z)	(9-17-85)
— —x— —	NA98502, LAGES TO FRANKFURT, DAY 260 (1118Z) TO (1526Z)	(9-17-85)
·····x·····	NA98503, FRANKFURT TO ANDREWS, DAY 261 (1054Z) TO (2015Z)	(9-18-85)



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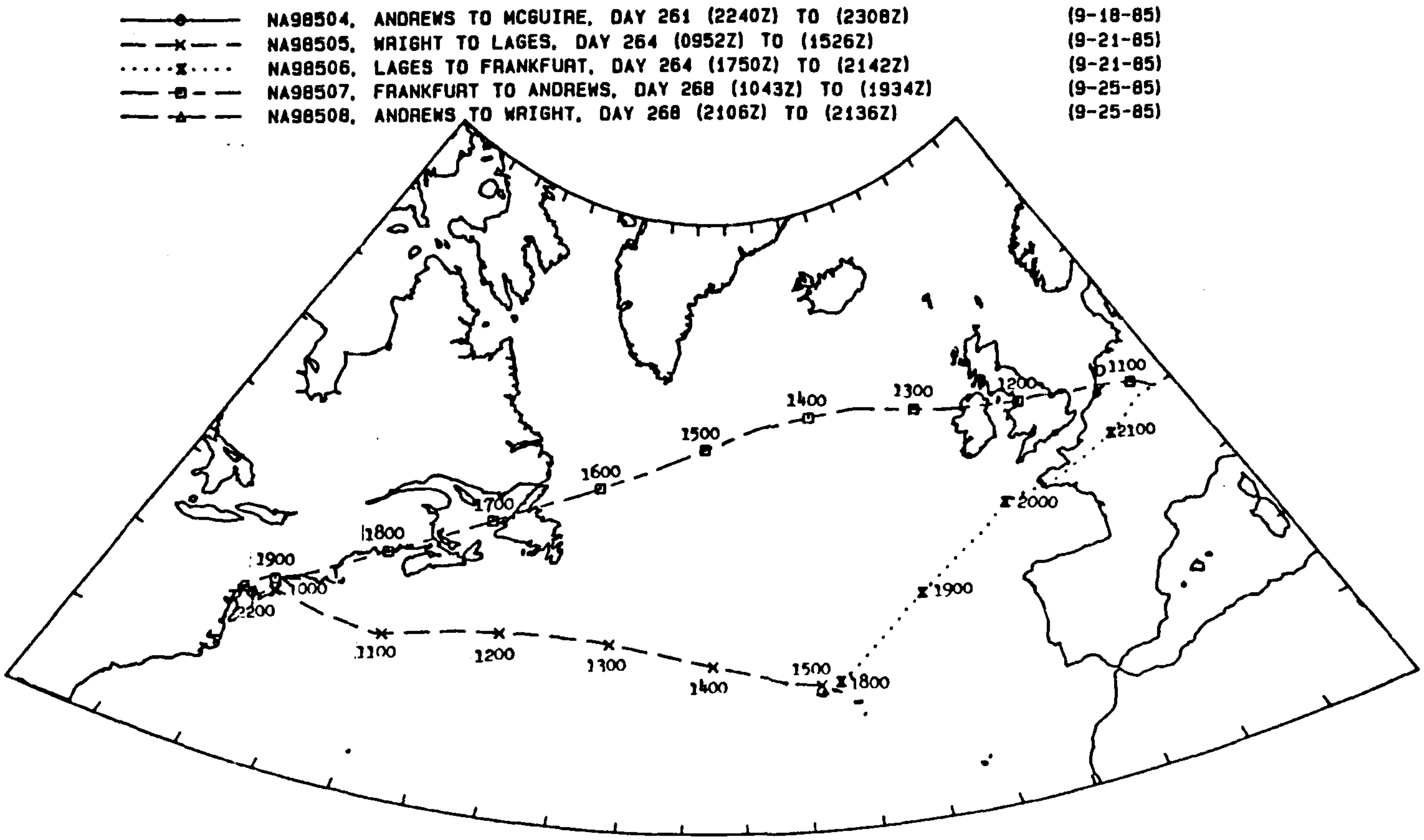


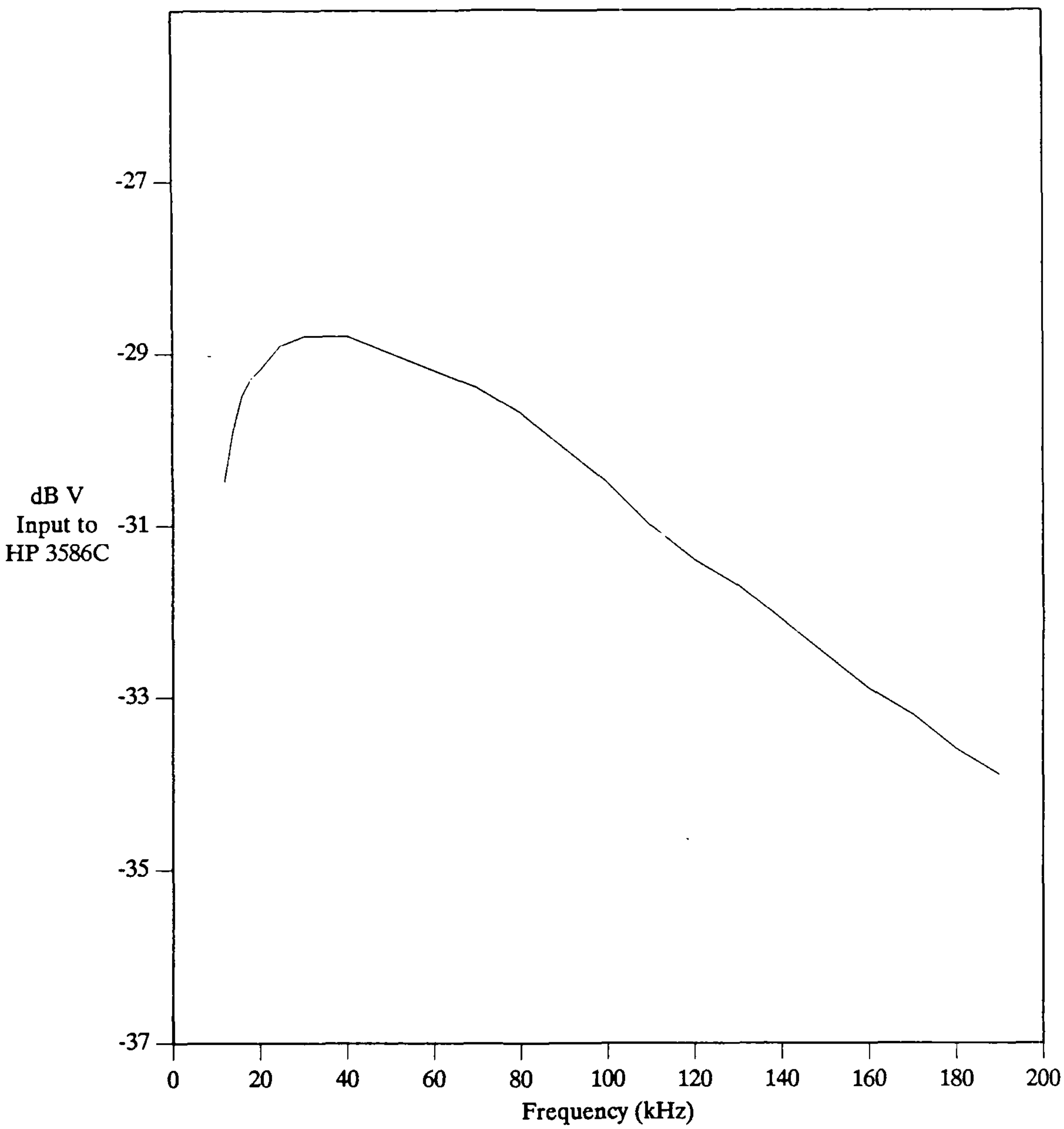
Coordinates are (85. 30.) (-10. 70.) (999.0 99.0)

APPENDIX B: PREAMPLIFIER FREQUENCY RESPONSE CURVES

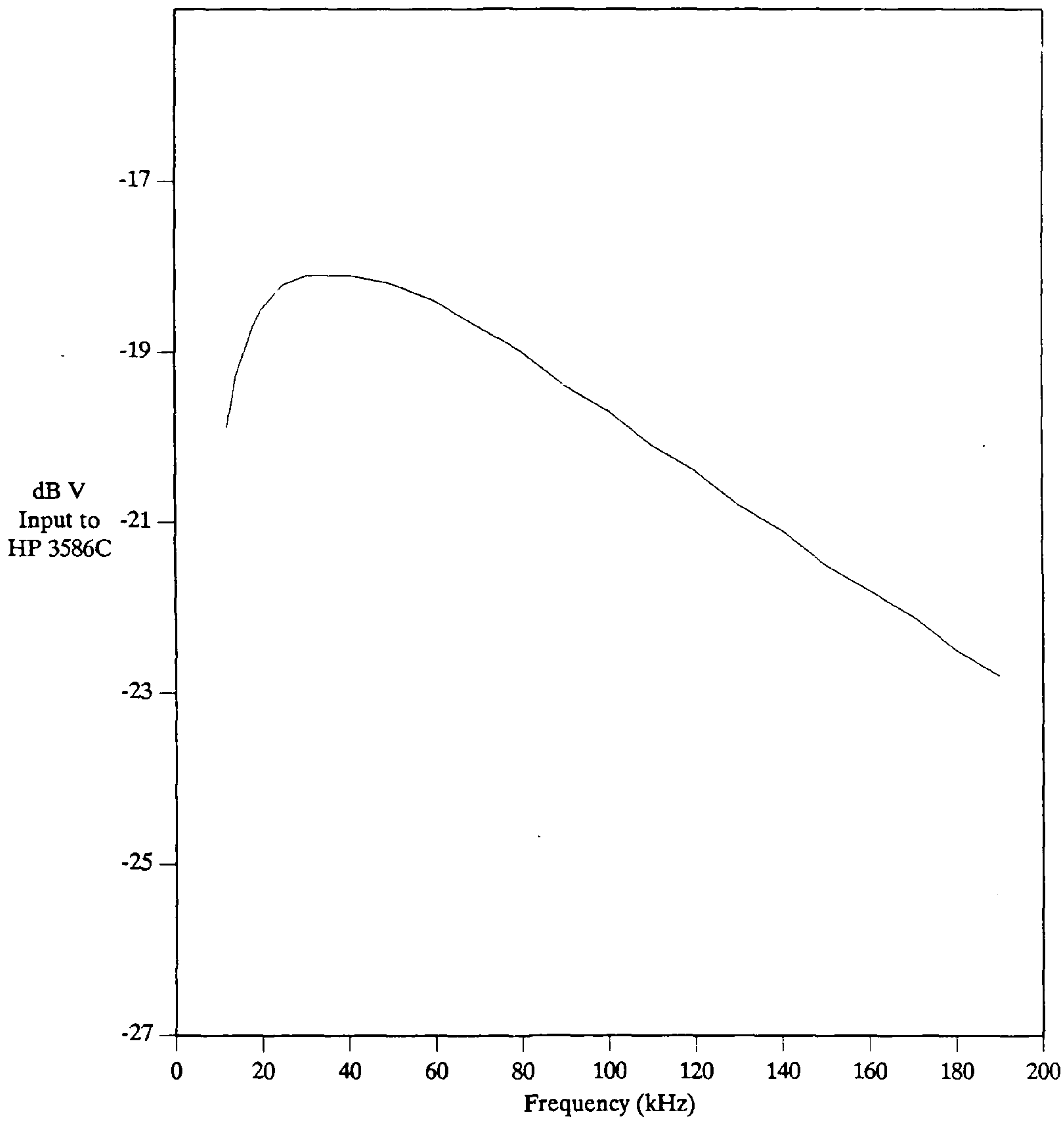
APPENDIX B

PAGE	FIGURE
1	Frequency response curve for preamp 1, tested 7-30-86.
2	Frequency response curve for preamp 2, tested 7-30-86.
3	Frequency response curve for preamp 8, tested 8-07-86.
4	Frequency response curve for MAC preamp 3.

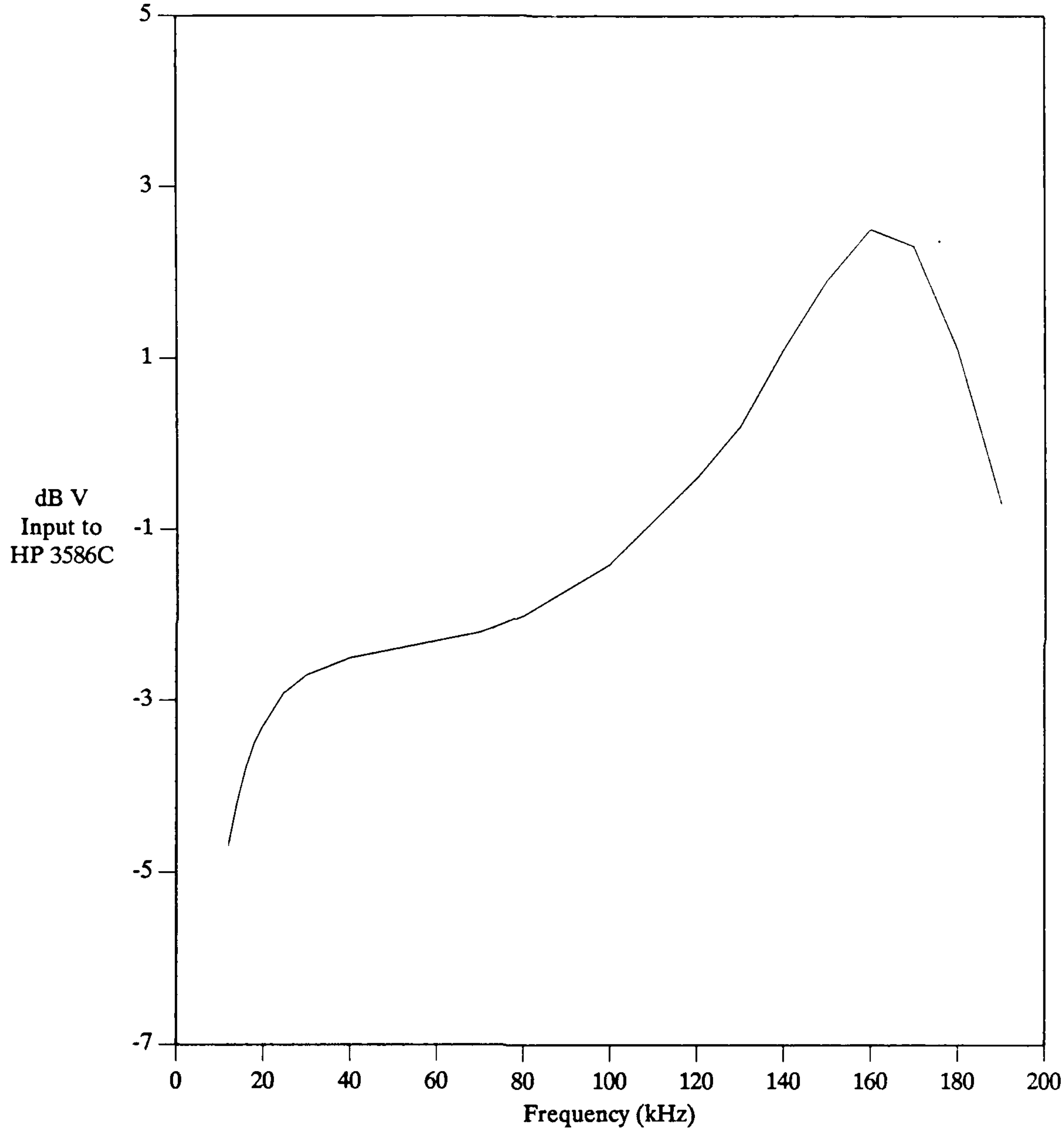
Frequency Response Curve for Preamp 1
Tested 7-30-86, Using a 50' RG-58 Cable on output



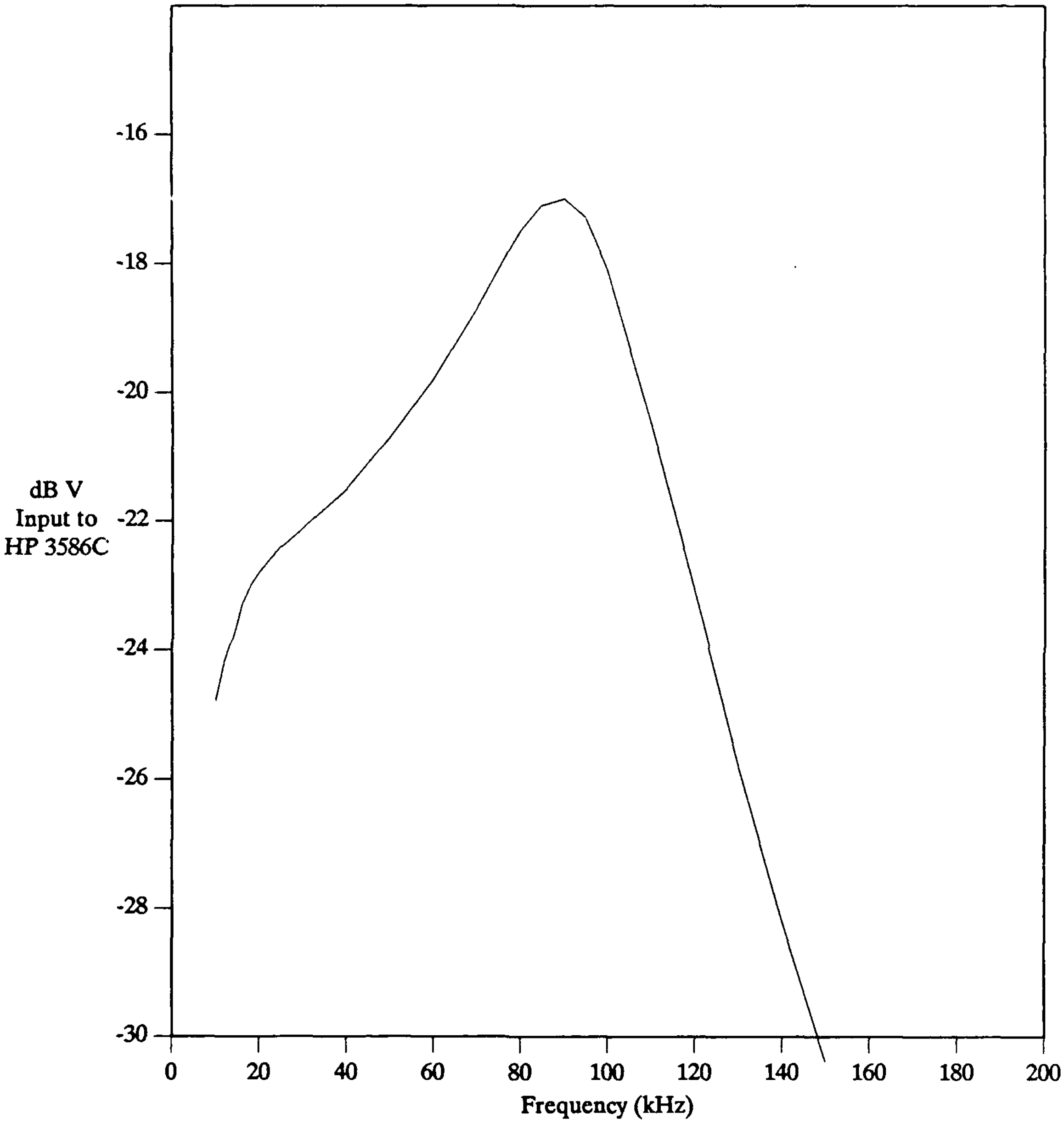
Frequency Response Curve for Preamp 2
Tested 7-30-86, Using a 50' RG-58 Cable on output



Frequency Response Curve for Preamp 8
Tested 8-07-86, Using a 50' RG-58 Cable on output



Frequency Response Curve for MAC Preamp 3



APPENDIX C: LOG DISTANCE PLOTS USED TO CALCULATE RADIATED POWER

Appendix C is Included With Volume 2

of the

GTS Callaghan/C-141 VLF/LF Data 1984-1986

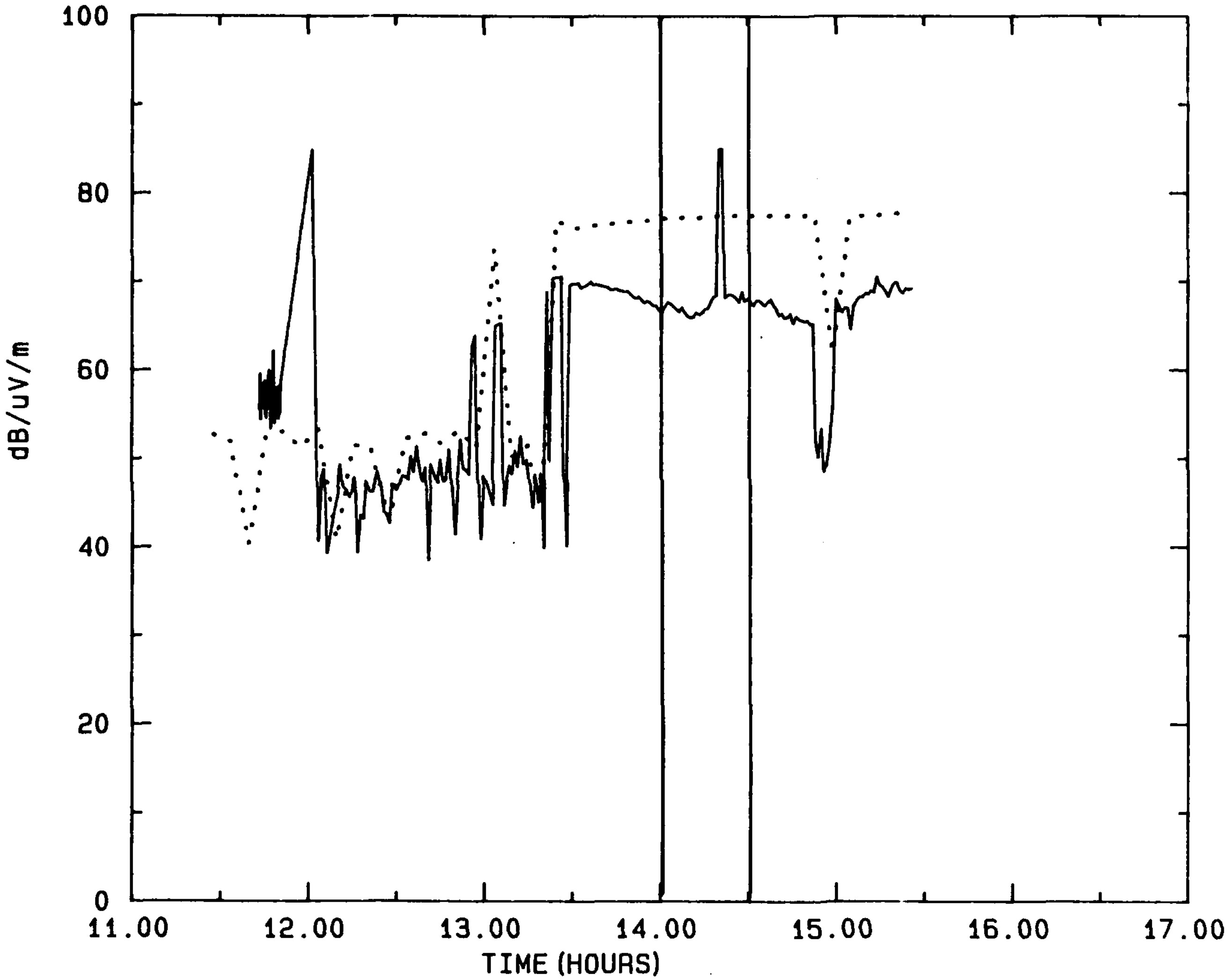
Report

Volume 2 is available on request from:
Naval Ocean Systems Center
271 Catalina Blvd
San Diego, CA 92152
CODE 542
619-553-3056

APPENDIX D: SIMULTANEOUS C-141 AND CALLAGHAN VLF/LF SIGNAL DATA

APPENDIX D

PAGE	FIGURE
1	Simultaneous Callaghan/Aircraft data at 16.0 kHz, on 9/17/85.
2	Simultaneous Callaghan/Aircraft data at 16.4 kHz, on 9/17/85.
3	Simultaneous Callaghan/Aircraft data at 19.0 kHz, on 9/17/85.
4	Simultaneous Callaghan/Aircraft data at 21.4 kHz, on 9/17/85.
5	Simultaneous Callaghan/Aircraft data at 24.0 kHz, on 9/17/85.
6	Simultaneous Callaghan/Aircraft data at 28.5 kHz, on 9/17/85.
7	Simultaneous Callaghan/Aircraft data at 16.4 kHz, on 9/18/85.
8	Simultaneous Callaghan/Aircraft data at 19.0 kHz, on 9/18/85.
9	Simultaneous Callaghan/Aircraft data at 21.4 kHz, on 9/18/85.
10	Simultaneous Callaghan/Aircraft data at 24.0 kHz, on 9/18/85.
11	Simultaneous Callaghan/Aircraft data at 28.5 kHz, on 9/18/85.
12	Simultaneous Callaghan/Aircraft data at 51.6 kHz, on 9/18/85.
13	Simultaneous Callaghan/Aircraft data at 55.5 kHz, on 9/18/85.
14	NOSC predicted signal level for 16.4 kHz.
15	NOSC predicted signal level for 19.0 kHz.
16	NOSC predicted signal level for 21.4 kHz.
17	NOSC predicted signal level for 24.0 kHz.
18	NOSC predicted signal level for 28.5 kHz.
19	NOSC predicted signal level for 55.5 kHz.



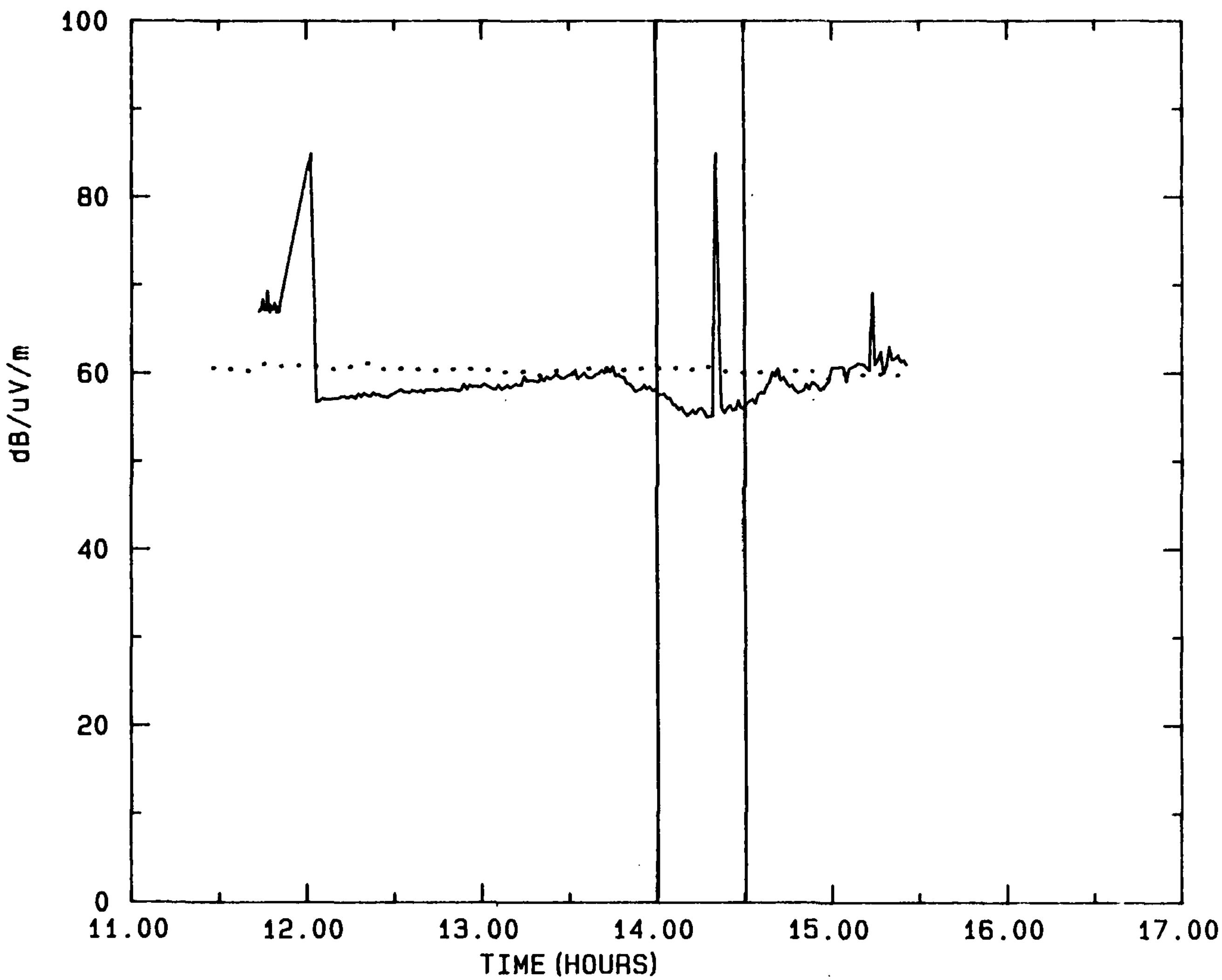
AIRCRAFT VS. CALLAGHAN

STATION FREQ = 16.00

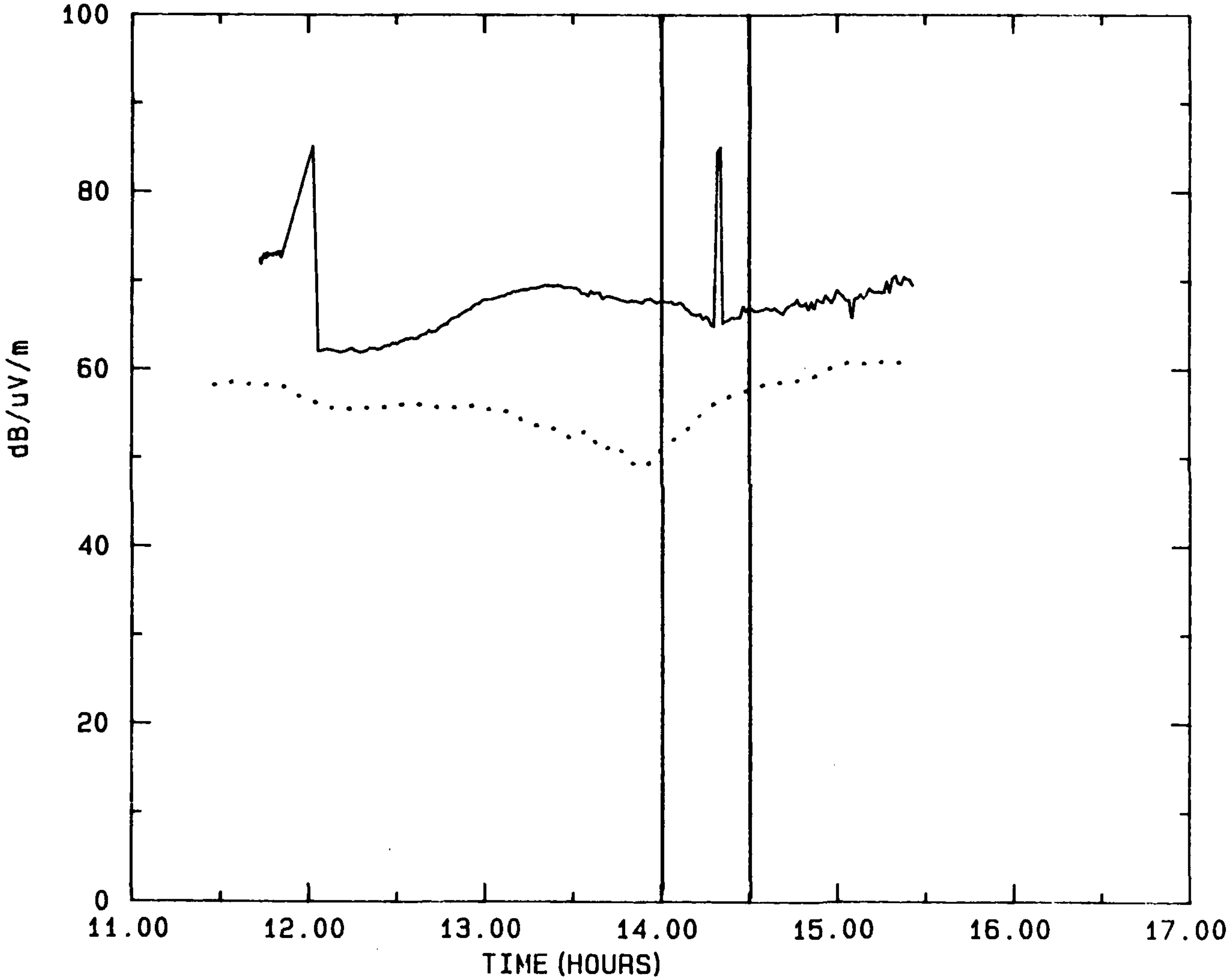
BEGIN : 09/17/85 AT 1118Z END : 09/17/85 AT 1526Z

AIRCRAFT DELTA dB 105.90 ————————

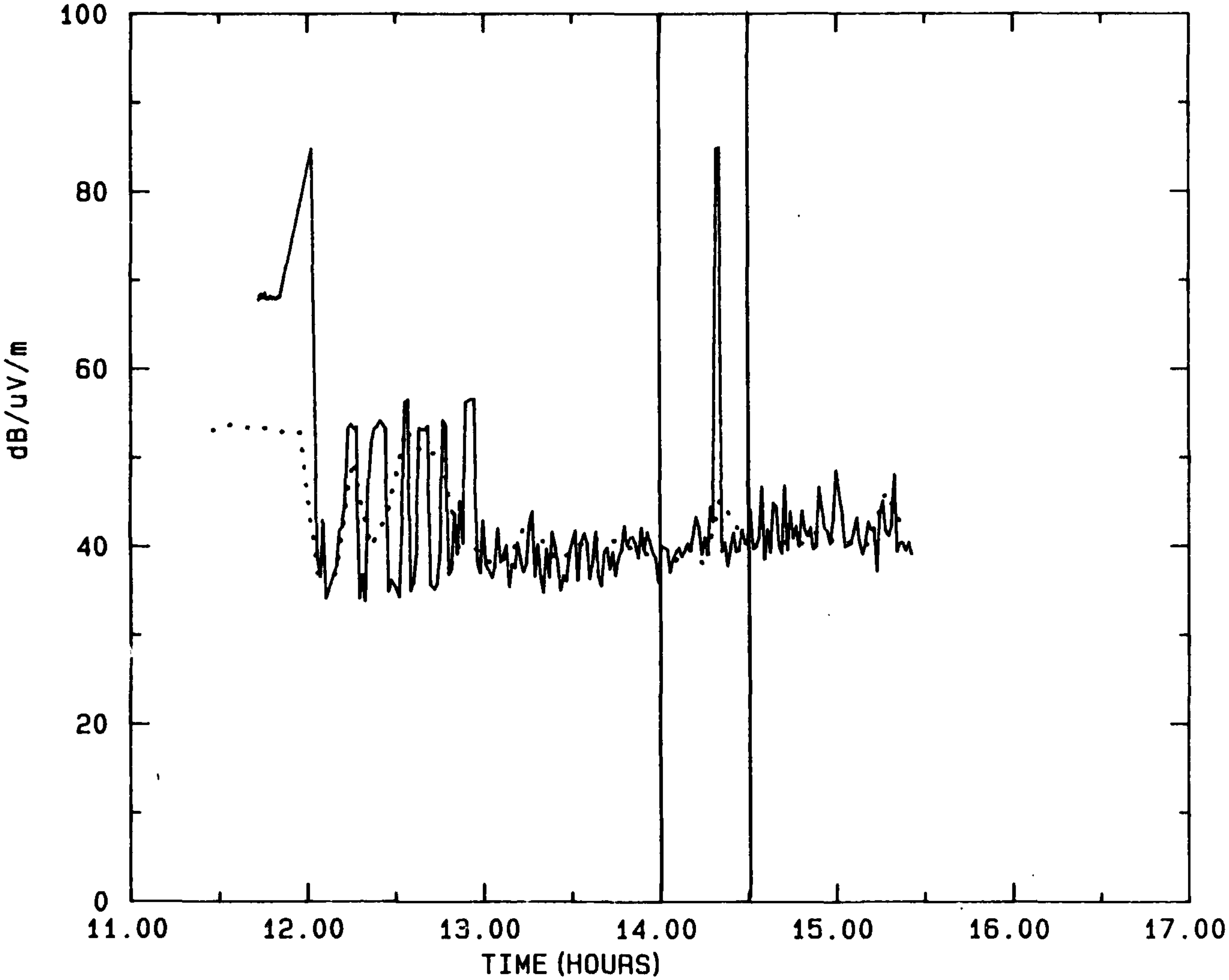
CALLAGHAN DELTA dB [illegible] . . . .



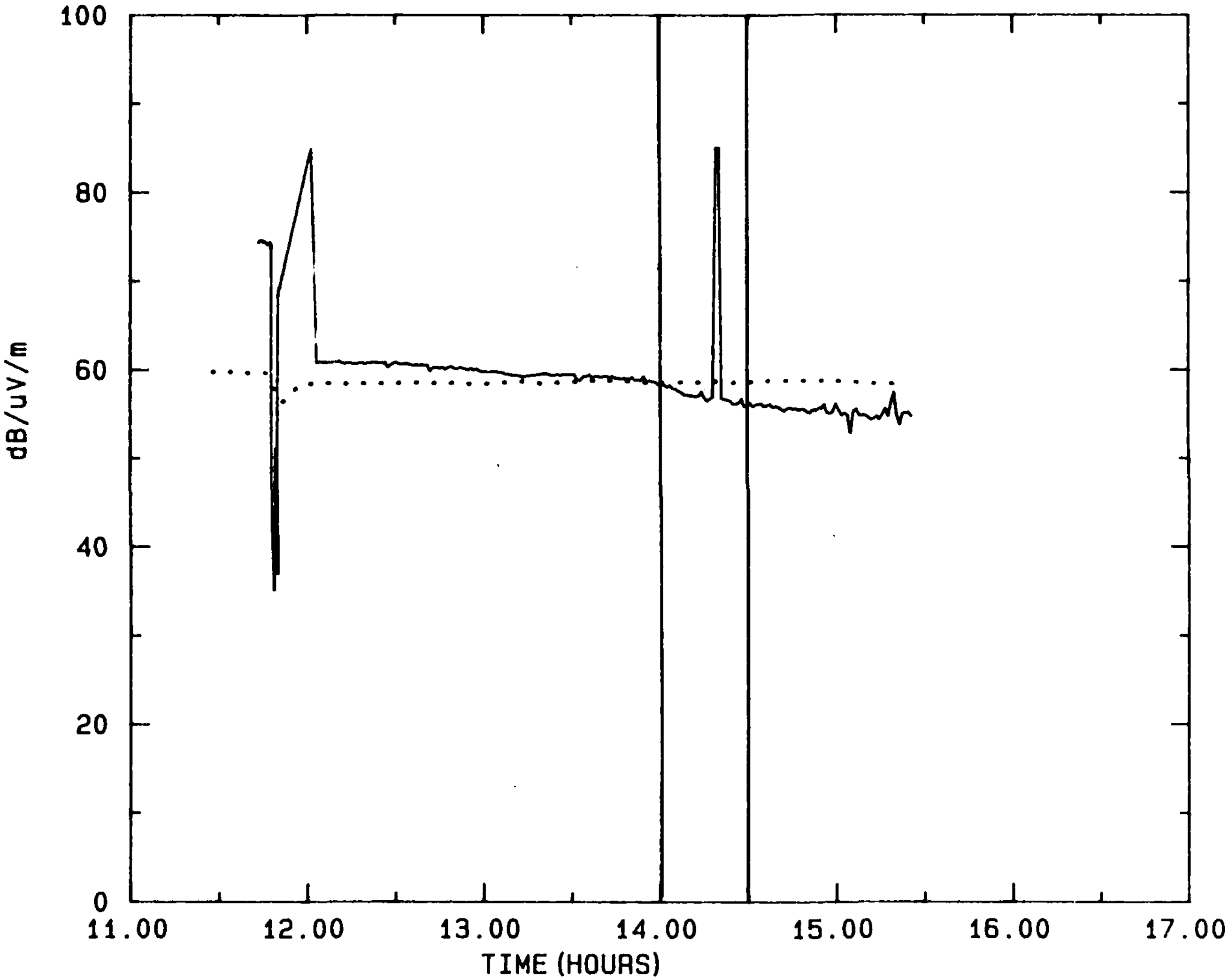
AIRCRAFT VS. CALLAGHAN
STATION FREQ = 16.40
BEGIN : 09/17/85 AT 1118Z END : 09/17/85 AT 1526Z
AIRCRAFT DELTA dB 105.90
CALLAGHAN DELTA dB [illegible]



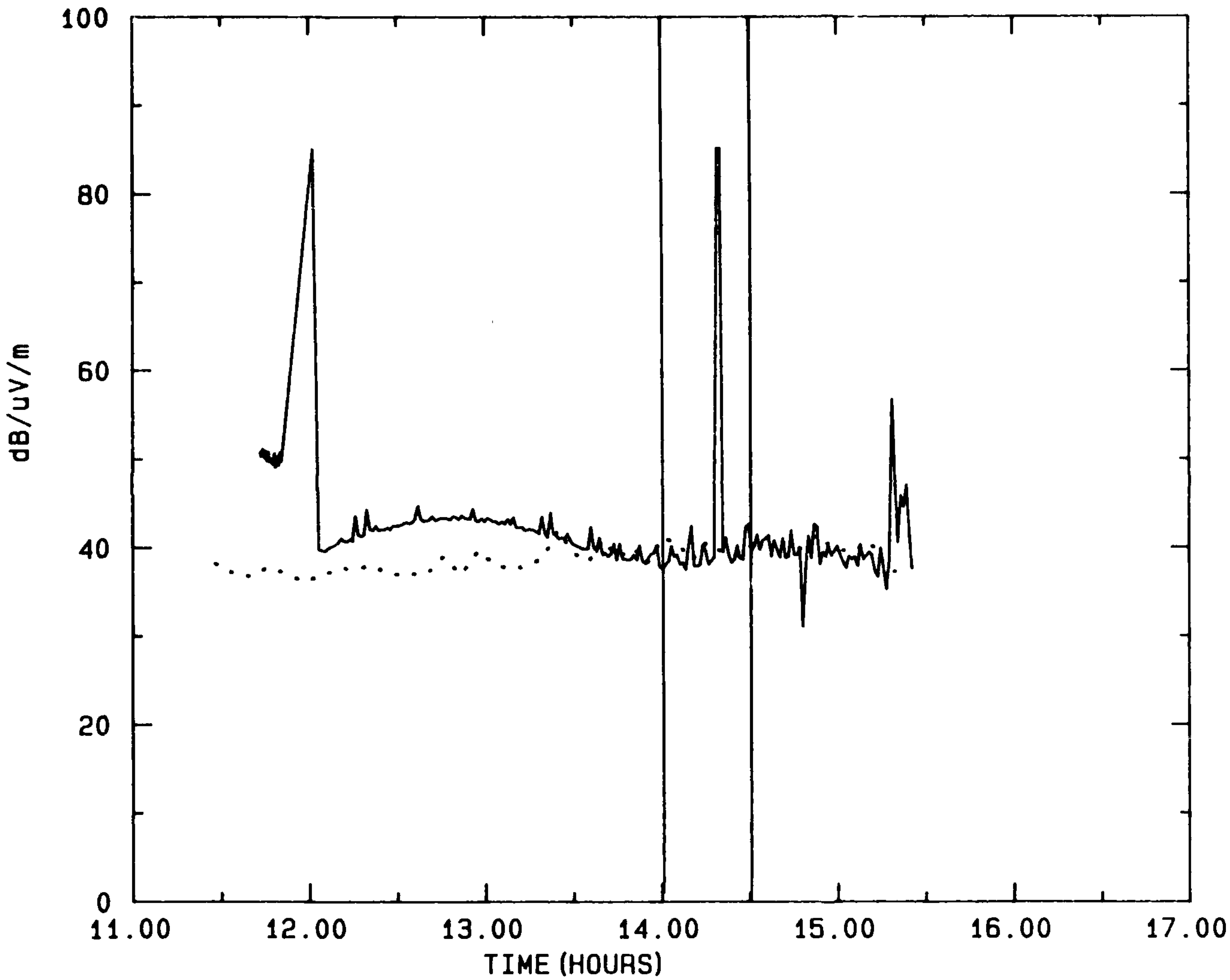
AIRCRAFT VS. CALLAGHAN
STATION FREQ = 19.00
BEGIN : 09/17/85 AT 1118Z END : 09/17/85 AT 1526Z
AIRCRAFT DELTA dB 105.60 ————
CALLAGHAN DELTA dB [illegible].10 ....



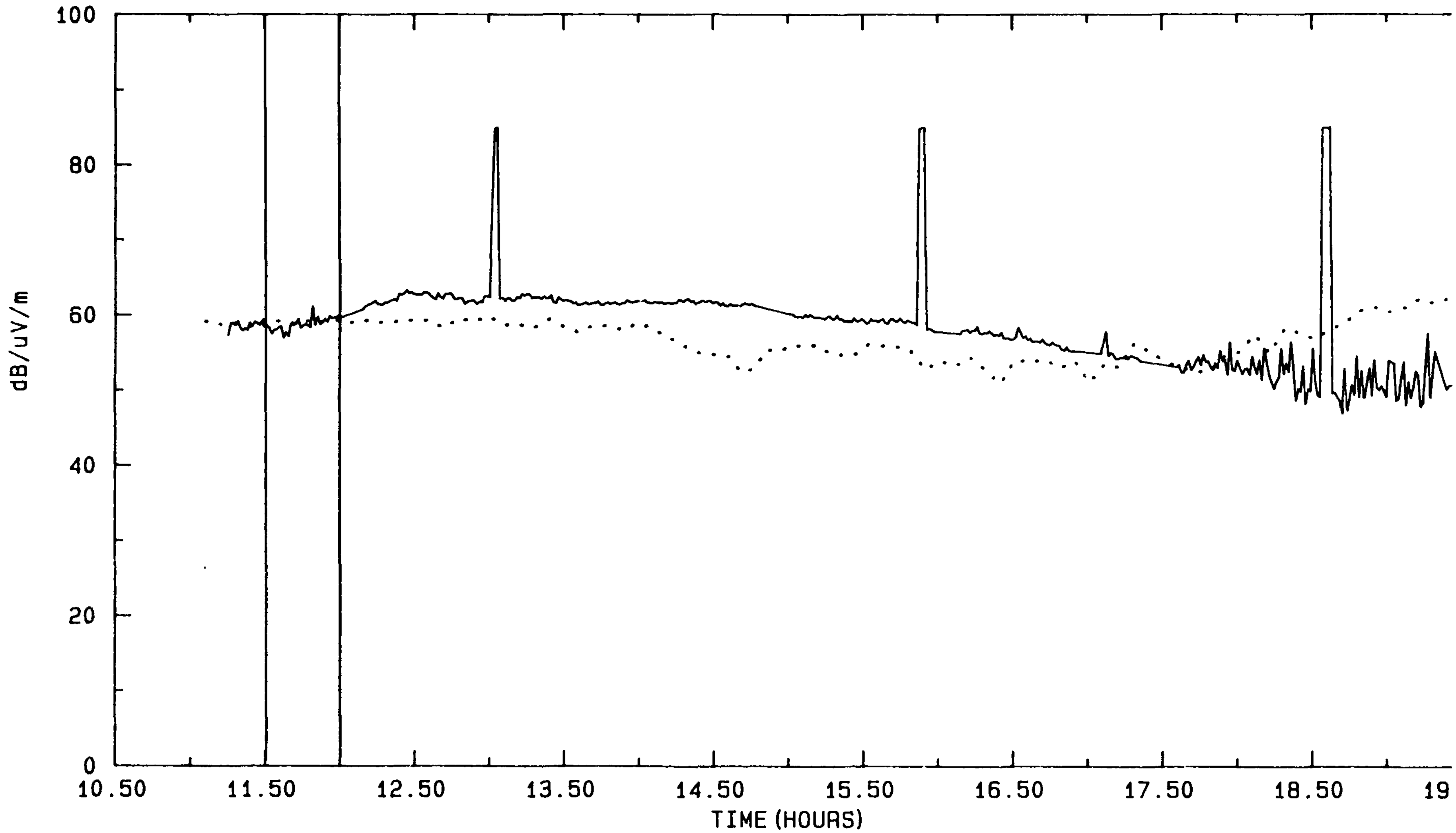
AIRCRAFT VS. CALLAGHAN
STATION FREQ = 21.40
BEGIN : 09/17/85 AT 1118Z END : 09/17/85 AT 1526Z
AIRCRAFT DELTA dB 105.30 ————
CALLAGHAN DELTA dB [illegible] ··········



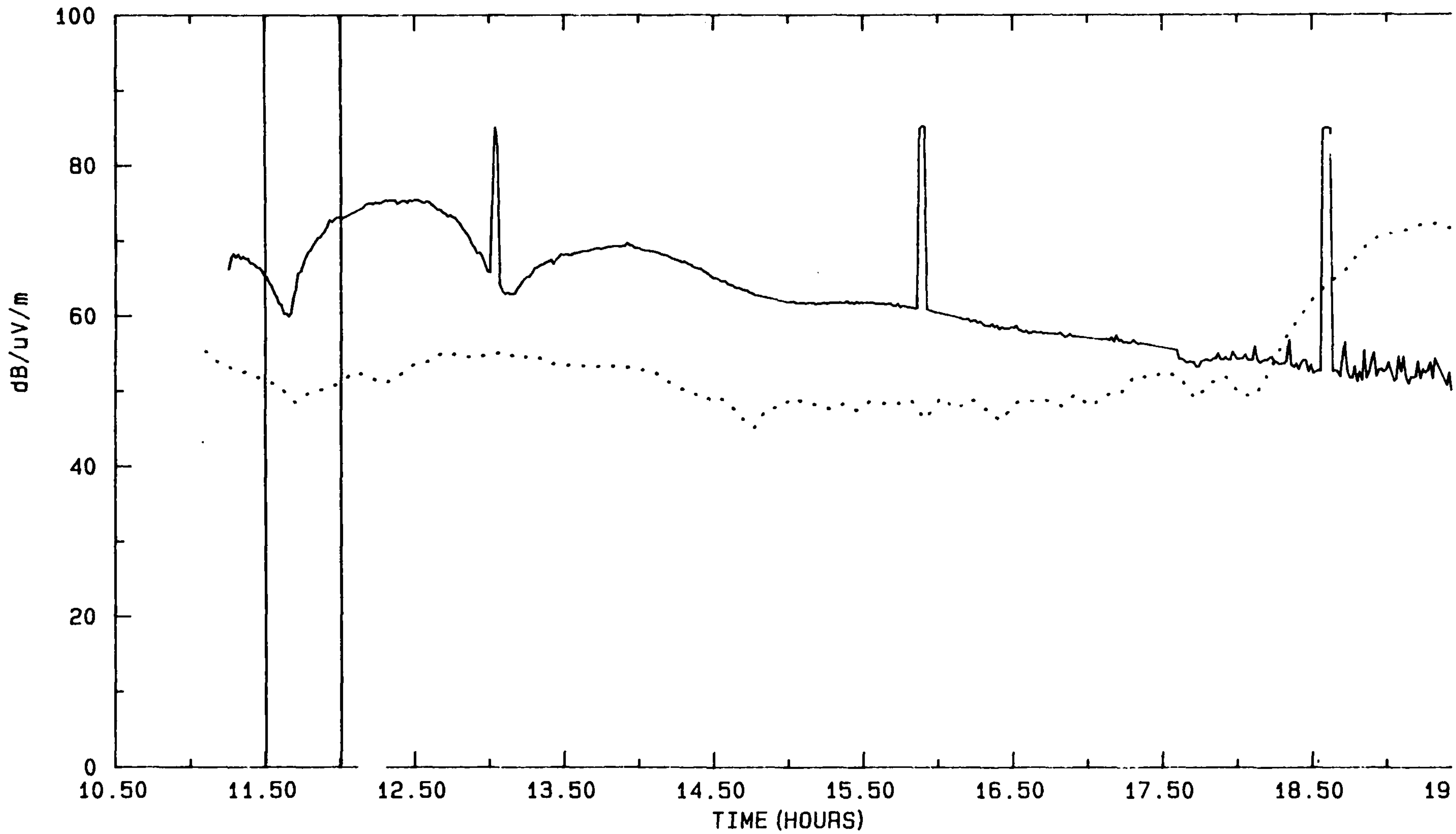
AIRCRAFT VS. CALLAGHAN
STATION FREQ = 24.00
BEGIN : 09/17/85 AT 1118Z END : 09/17/85 AT 1526Z
AIRCRAFT DELTA dB 105.20 ————————
CALLAGHAN DELTA dB [illegible] ....



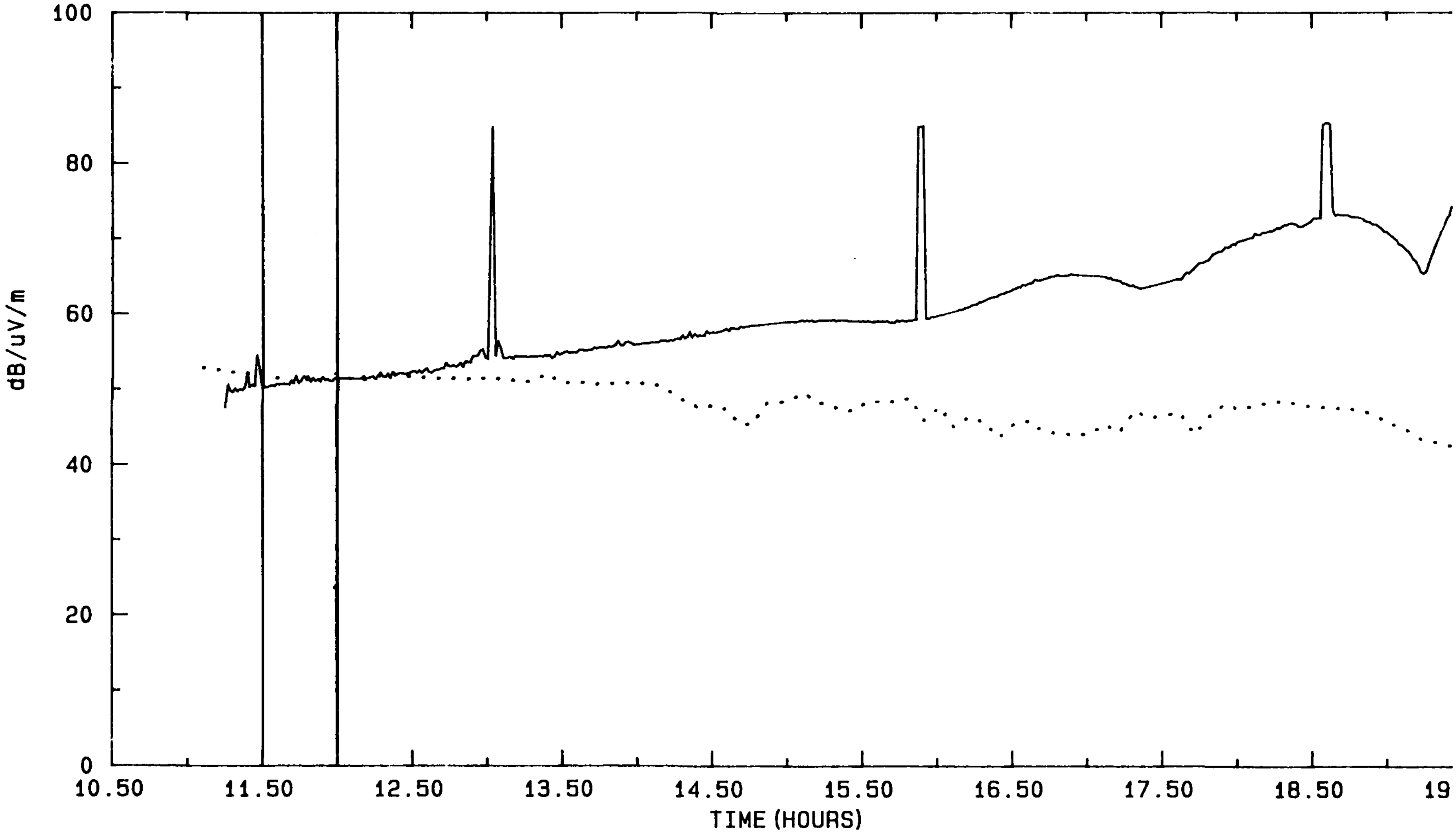
AIRCRAFT VS. CALLAGHAN
STATION FREQ = 28.50
BEGIN : 09/17/85 AT 1118Z END : 09/17/85 AT 1526Z
AIRCRAFT DELTA dB 105.00 ————
CALLAGHAN DELTA dB [illegible] . . . .

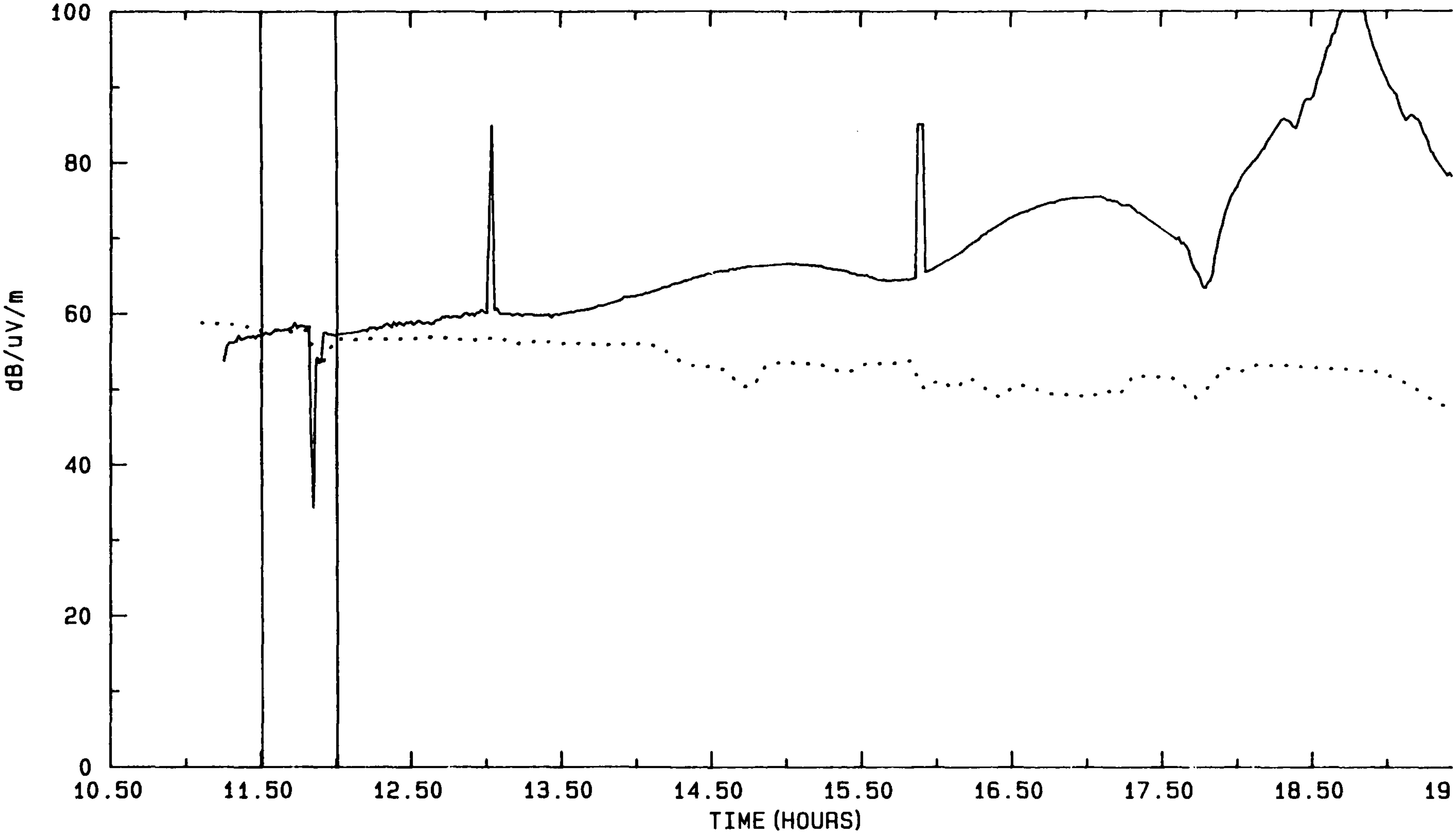


AIRCRAFT VS. CALLAGHAN
STATION FREQ = 16.40
BEGIN : 09/18/85 AT 1054Z END : 09/18/85 AT 2015Z
AIRCRAFT DELTA dB 105.90 ————
CALLAGHAN DELTA dB [illegible] . . . .

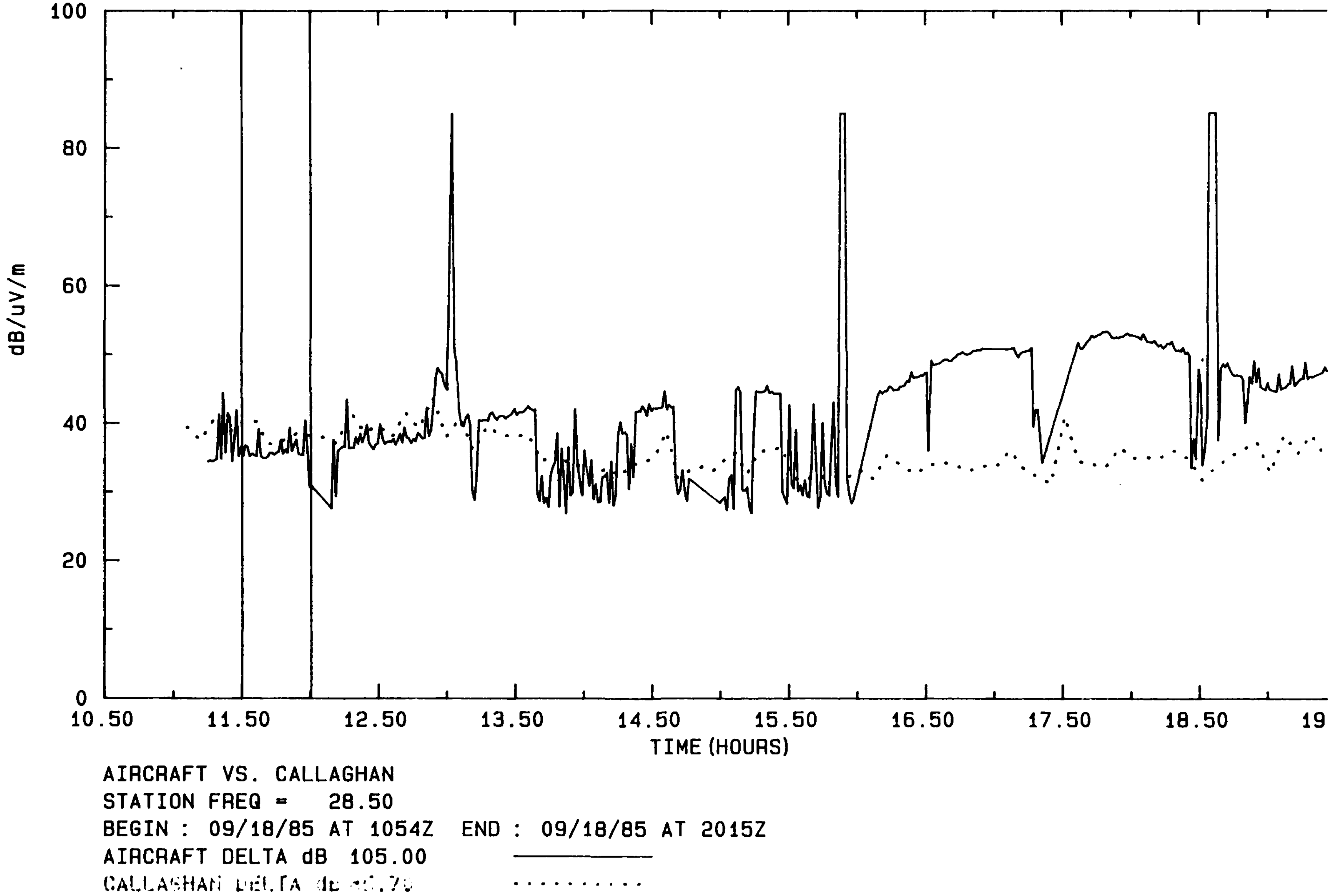


AIRCRAFT VS. CALLAGHAN
STATION FREQ = 19.00
BEGIN : 09/18/85 AT 1054Z END : 09/18/85 AT 2015Z
AIRCRAFT DELTA dB 105.60 ————
CALLAGHAN DELTA dB [illegible] ··········

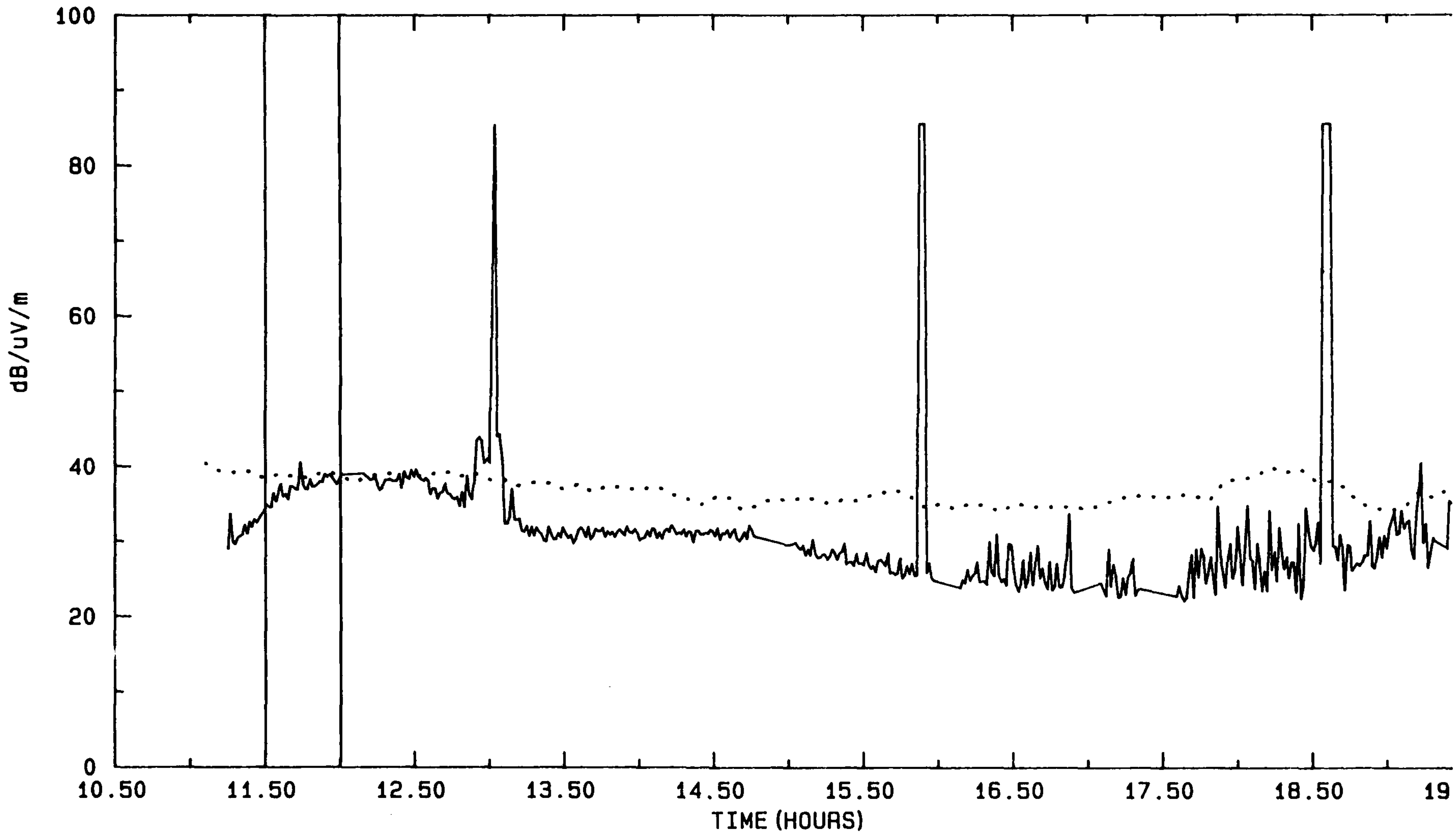

100
80
60
40
20
0
dB/uV/m
10.50
11.50
12.50
13.50
14.50
15.50
16.50
17.50
18.50
19
TIME (HOURS)
AIRCRAFT VS. CALLAGHAN
STATION FREQ = 21.40
BEGIN : 09/18/85 AT 1054Z END : 09/18/85 AT 2015Z
AIRCRAFT DELTA dB 105.30
CALLAGHAN DELTA db [illegible]



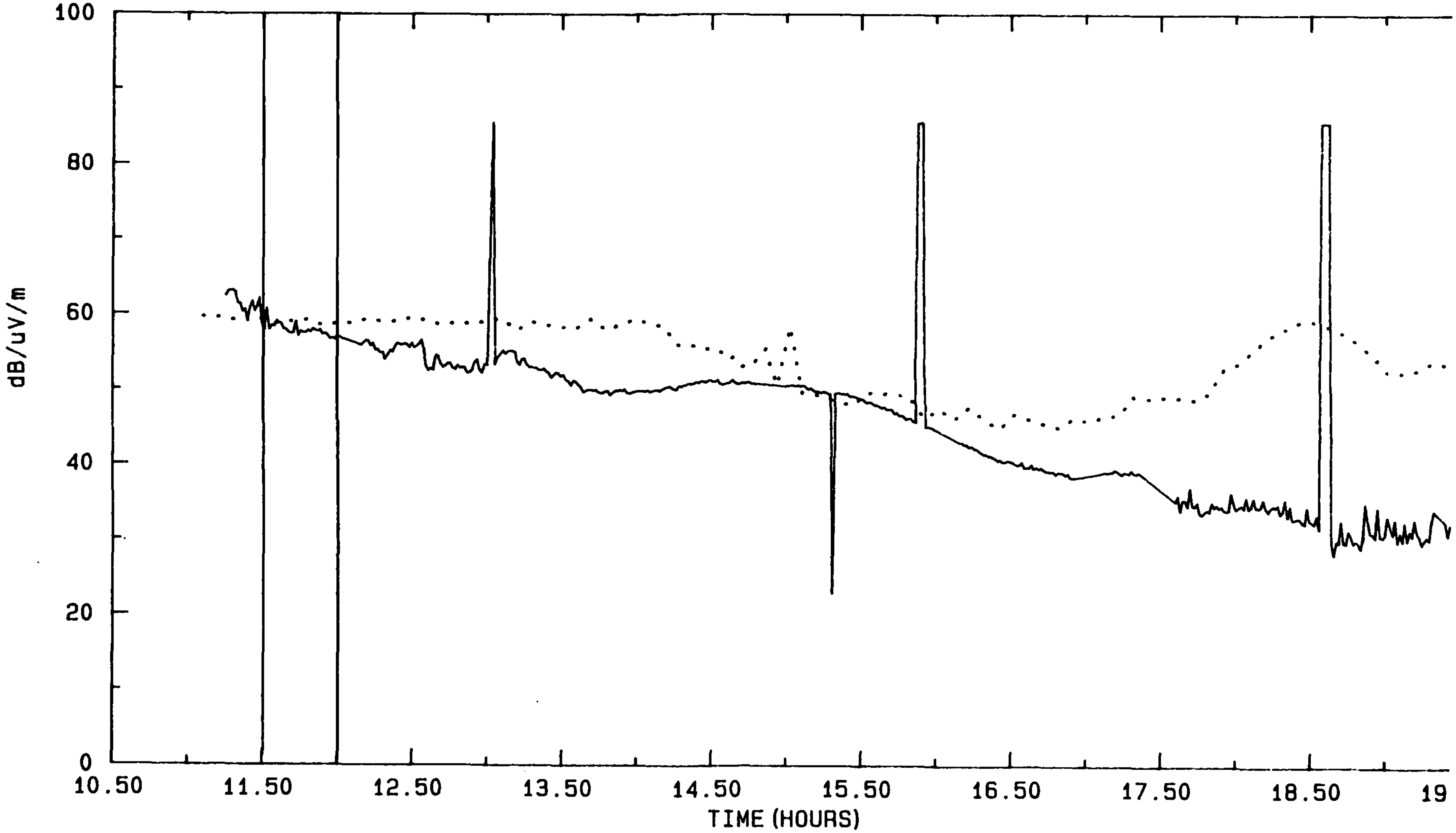
AIRCRAFT VS. CALLAGHAN
STATION FREQ = 24.00
BEGIN : 09/18/85 AT 1054Z END : 09/18/85 AT 2015Z
AIRCRAFT DELTA dB 105.20 ————————
CALLAGHAN DELTA dB [illegible] . . . .



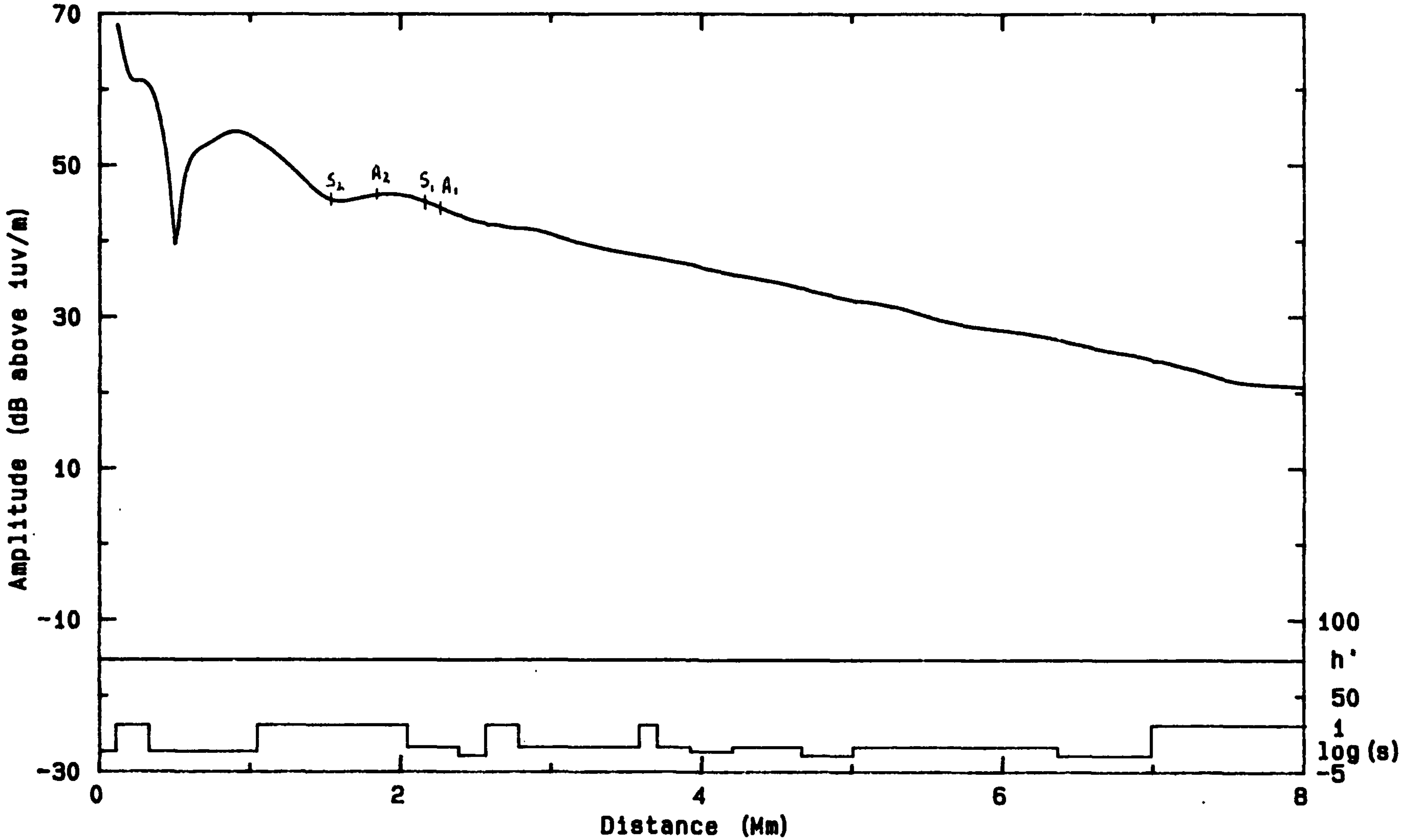
100
80
60
40
20
0
dB/uV/m
10.50
11.50
12.50
13.50
14.50
15.50
16.50
17.50
18.50
19
TIME (HOURS)
AIRCRAFT VS. CALLAGHAN
STATION FREQ = 28.50
BEGIN : 09/18/85 AT 1054Z END : 09/18/85 AT 2015Z
AIRCRAFT DELTA dB 105.00
CALLAGHAN DELTA dB



AIRCRAFT VS. CALLAGHAN
STATION FREQ = 51.60
BEGIN : 09/18/85 AT 1054Z END : 09/18/85 AT 2015Z
AIRCRAFT DELTA dB 103.70
CALLAGHAN DELTA dB [illegible]



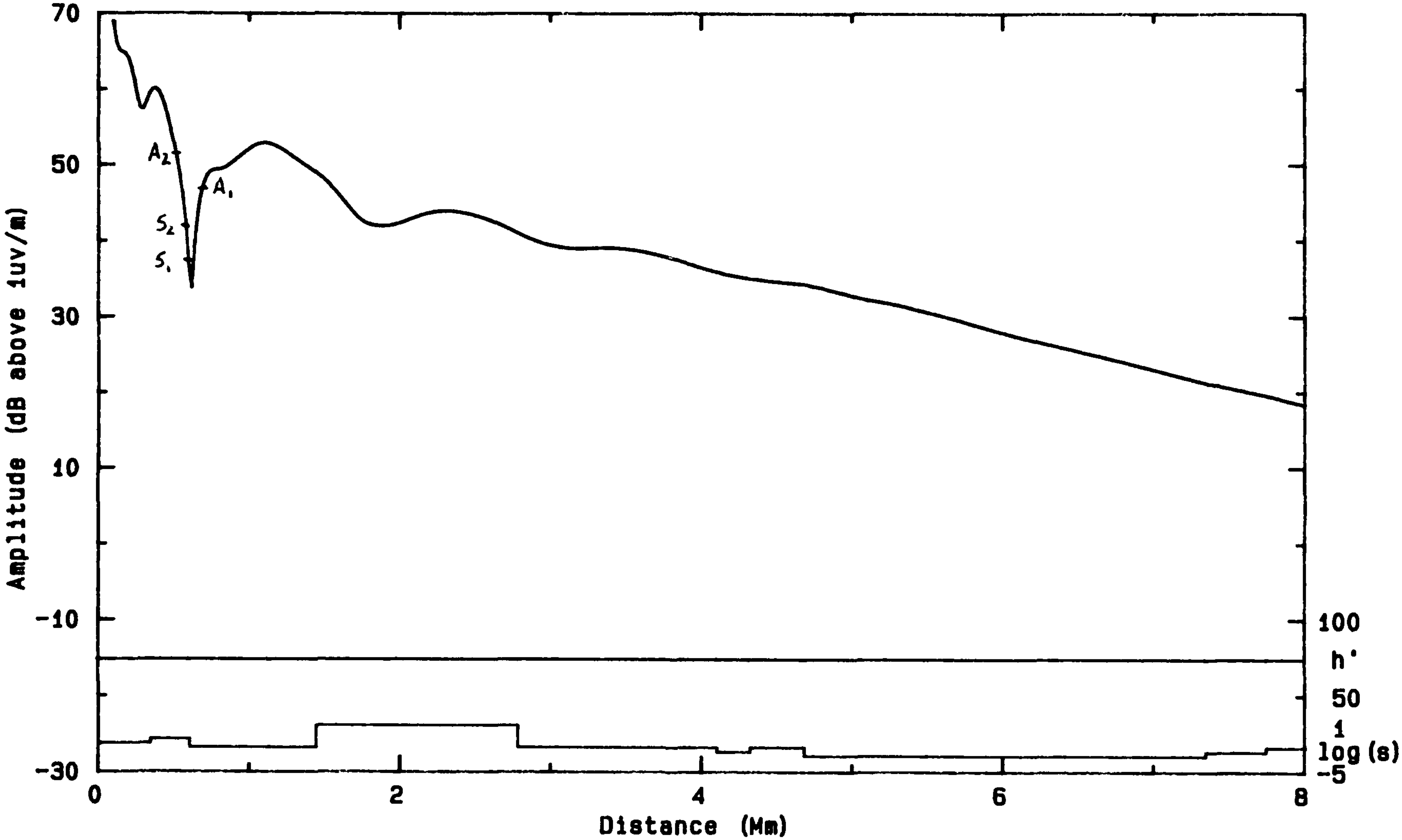
AIRCRAFT VS. CALLAGHAN
STATION FREQ = 55.50
BEGIN : 09/18/85 AT 1054Z END : 09/18/85 AT 2015Z
AIRCRAFT DELTA dB 103.40 ————
CALLAGHAN DELTA dB [illegible] ....



noviken to dover

xmtr_id	freq	tlat	tlon	brng	pwr	in	hdg	talt	ralt
nov_dov	16.4	67.0	-13.9	207.5	1	0	0.0	0.0	0.0

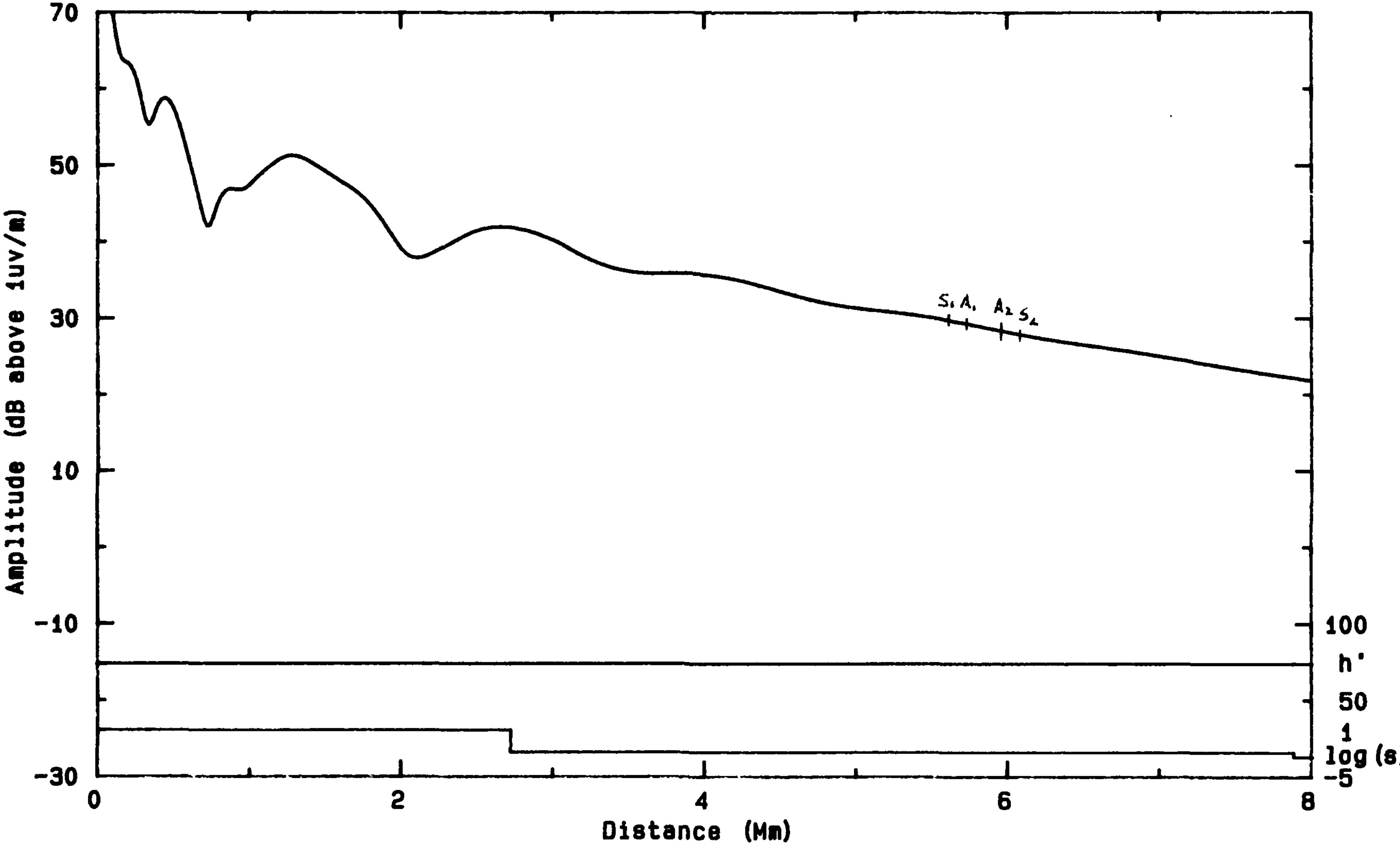
Prfl: All day
File: NOV_DOV.lwf
Prgm: mf_sw run on 7-DEC-88



anthorn to dover

xmtr_id	freq	tlat	tlon	brng	pwr	in	hdg	talt	ralt
ant_dov	19.0	54.9	3.3	144.9	1	0	0.0	0.0	0.0

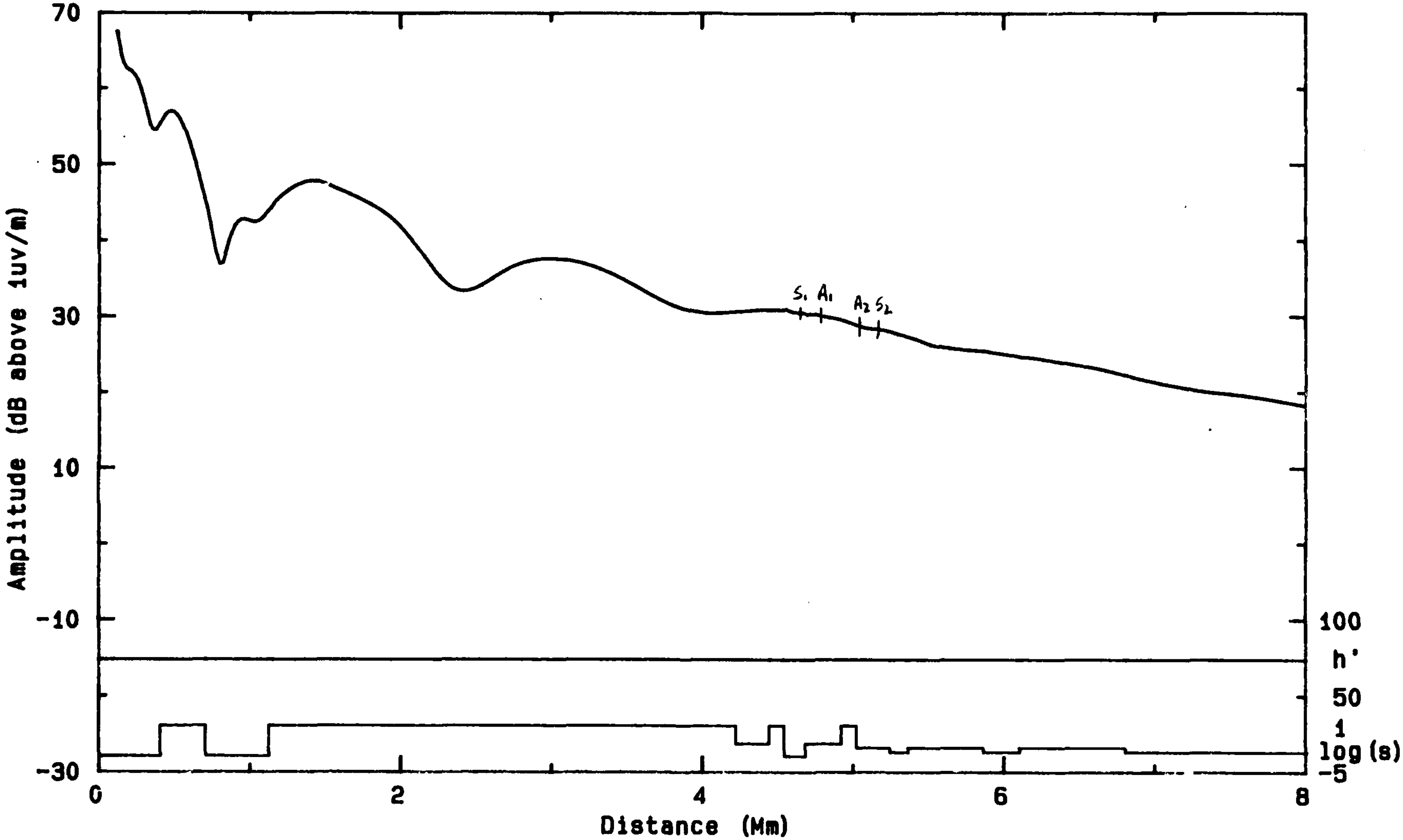
Prfl: All day
File: ANT_DOV.lwf
Prgm: mf_sw run on 7-DEC-88



ann21apolis to dover

xmtr_id	freq	tlat	tlon	brng	pwr	in	hdg	talt	ralt
ann21_do	21.4	39.0	27.5	50.3	1	0	0.0	0.0	0.0

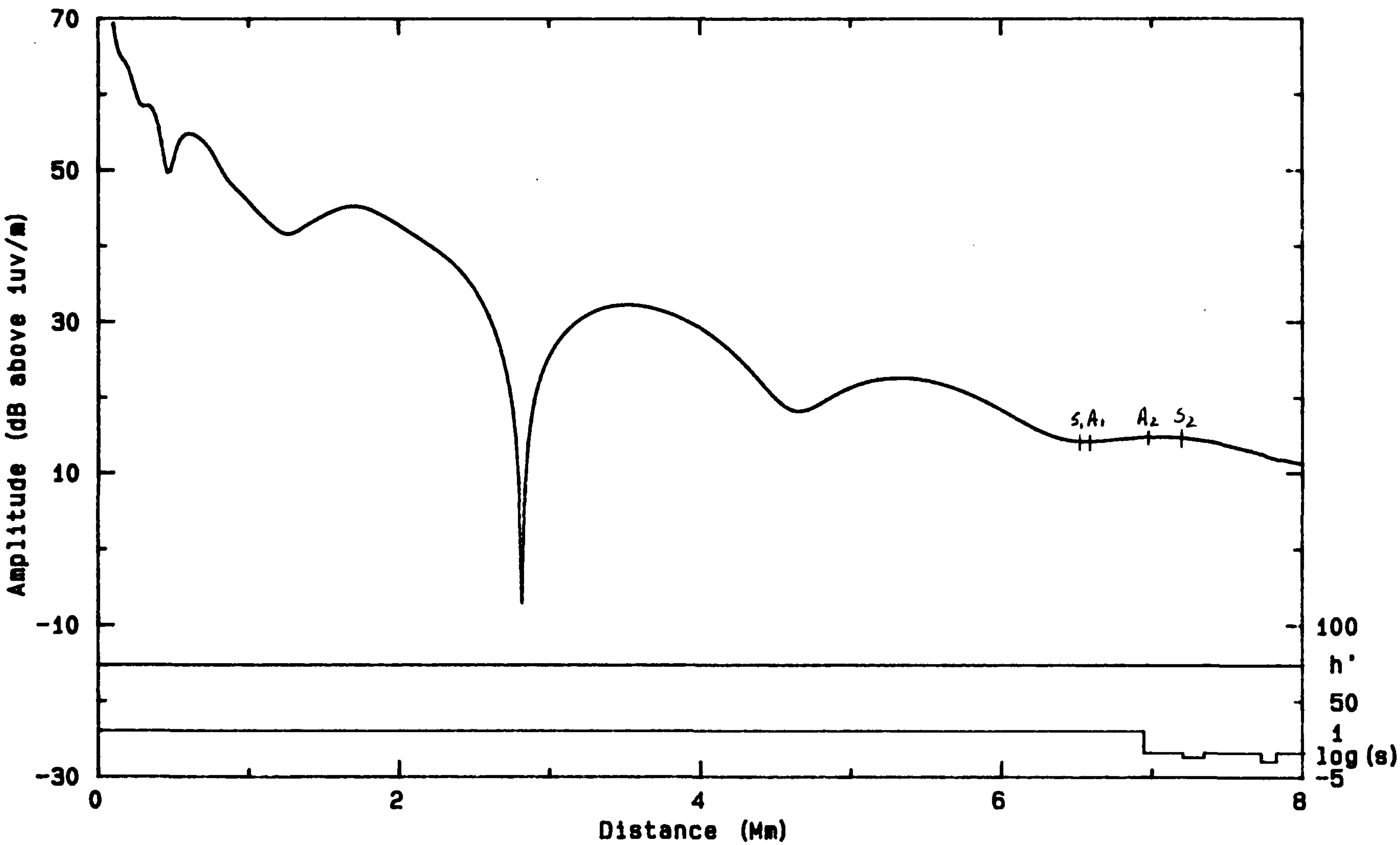
Prfl: All day
File: ANN21_DOV.lwf
Prgm: mf_sw run on 7-DEC-88



cutler to dover

xmtr_id	freq	tlat	tlon	brng	pwr	in	hdg	talt	ralt
cut_dov	24.0	44.7	67.3	56.6	1	0	0.0	0.0	0.0

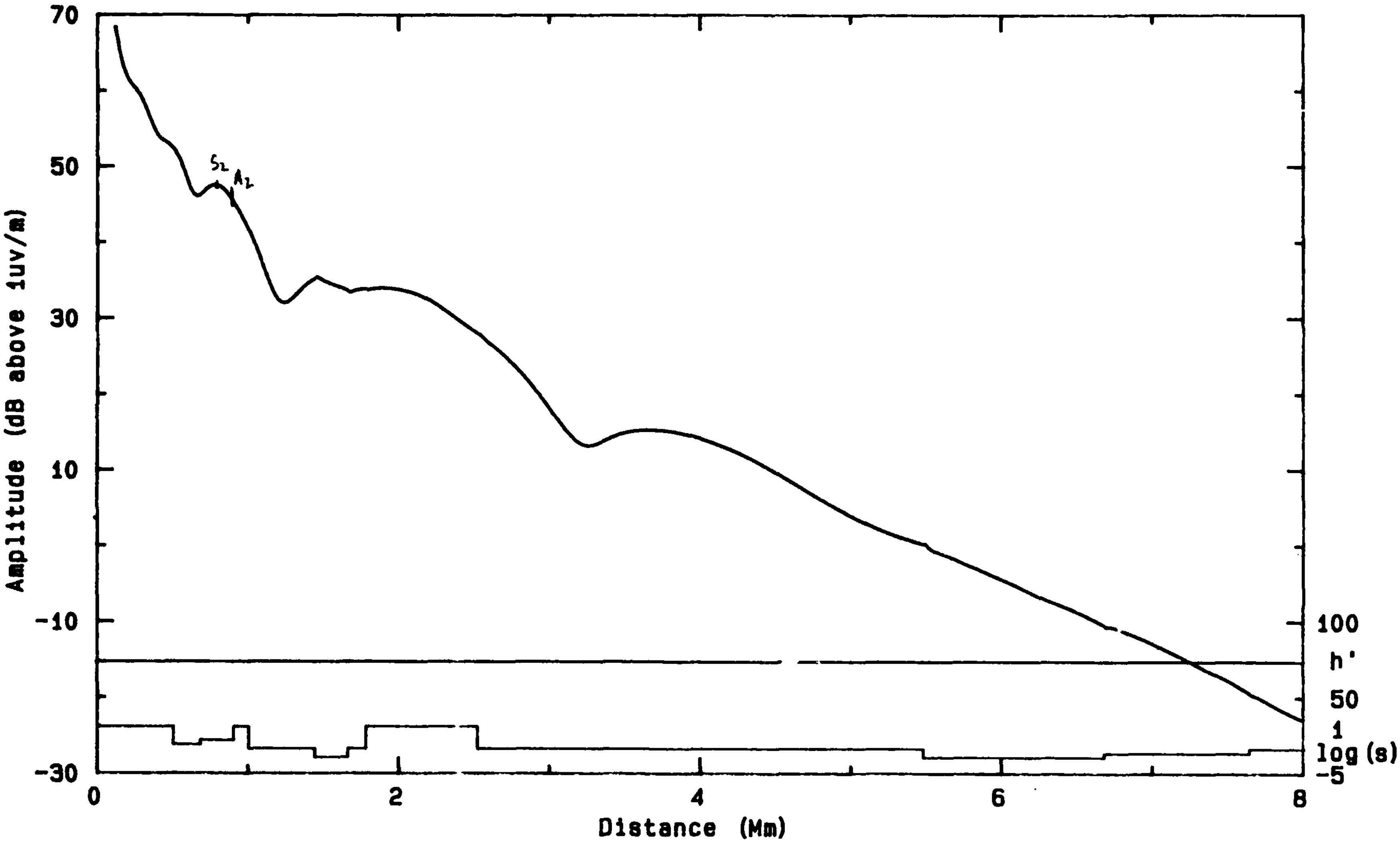
Prfl: All day
File: CUT_DOV.lwf
Prgm: mf_sw run on 7-DEC-88



agu   to dover

xmtr_id	freq	tlat	tlon	brng	pwr	in	hdg	talt	ralt
agu_dov	28.5	18.4	67.2	41.7	1	0	0.0	0.0	0.0

Prfl: All day
File: agu_dov.lwf
Prgm: mf_sw   run on 7-DEC-88



thu to dover

xmtr_id	freq	tlat	tlon	brng	pwr	in	hdg	talt	ralt
thu_dov	55.5	58.6	3.7	158.1	1	0	0.0	0.0	0.0

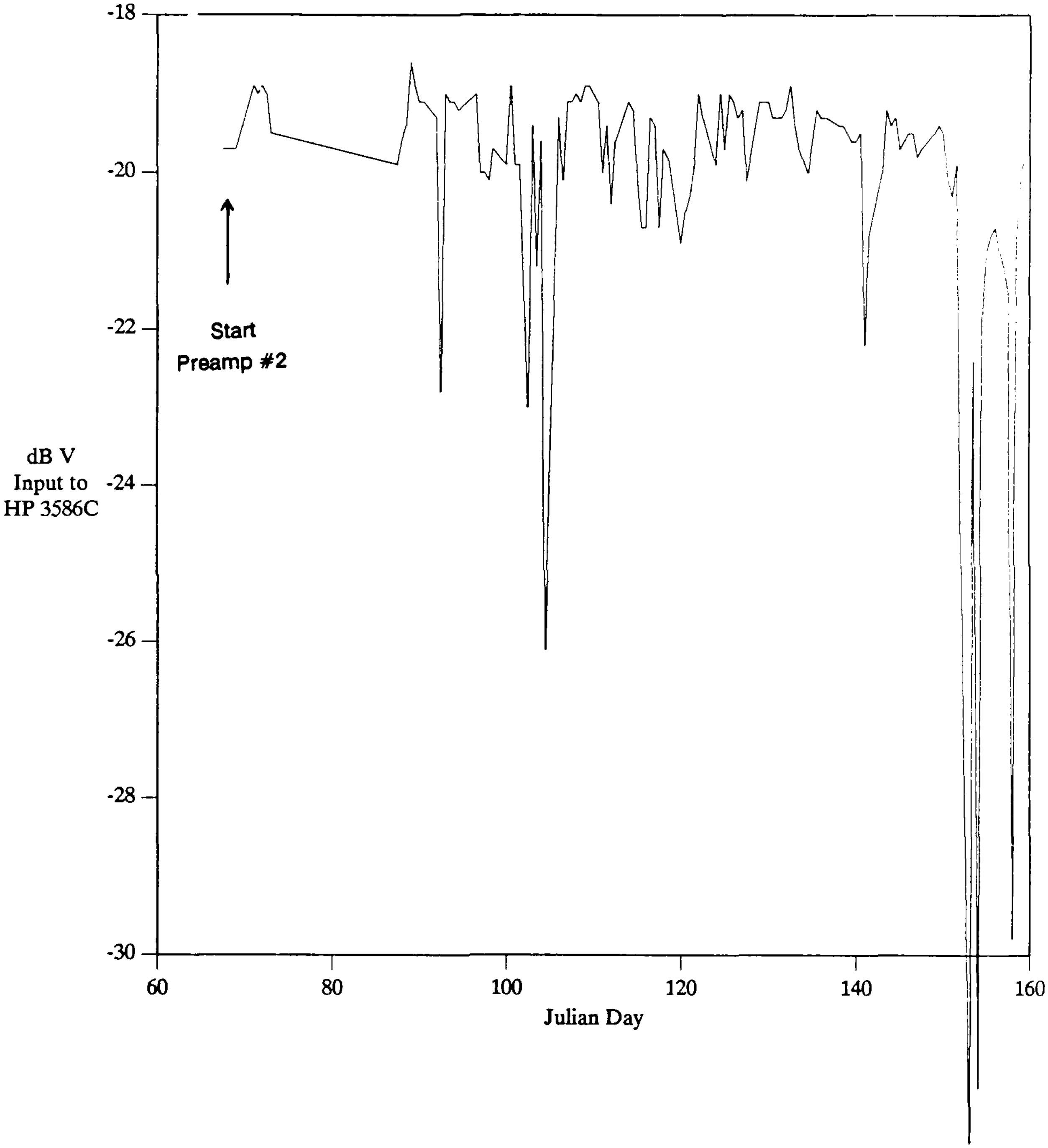
Prfl: All day
File: THU_DOV.lwf
Prgm: mf_sw run on 7-DEC-88

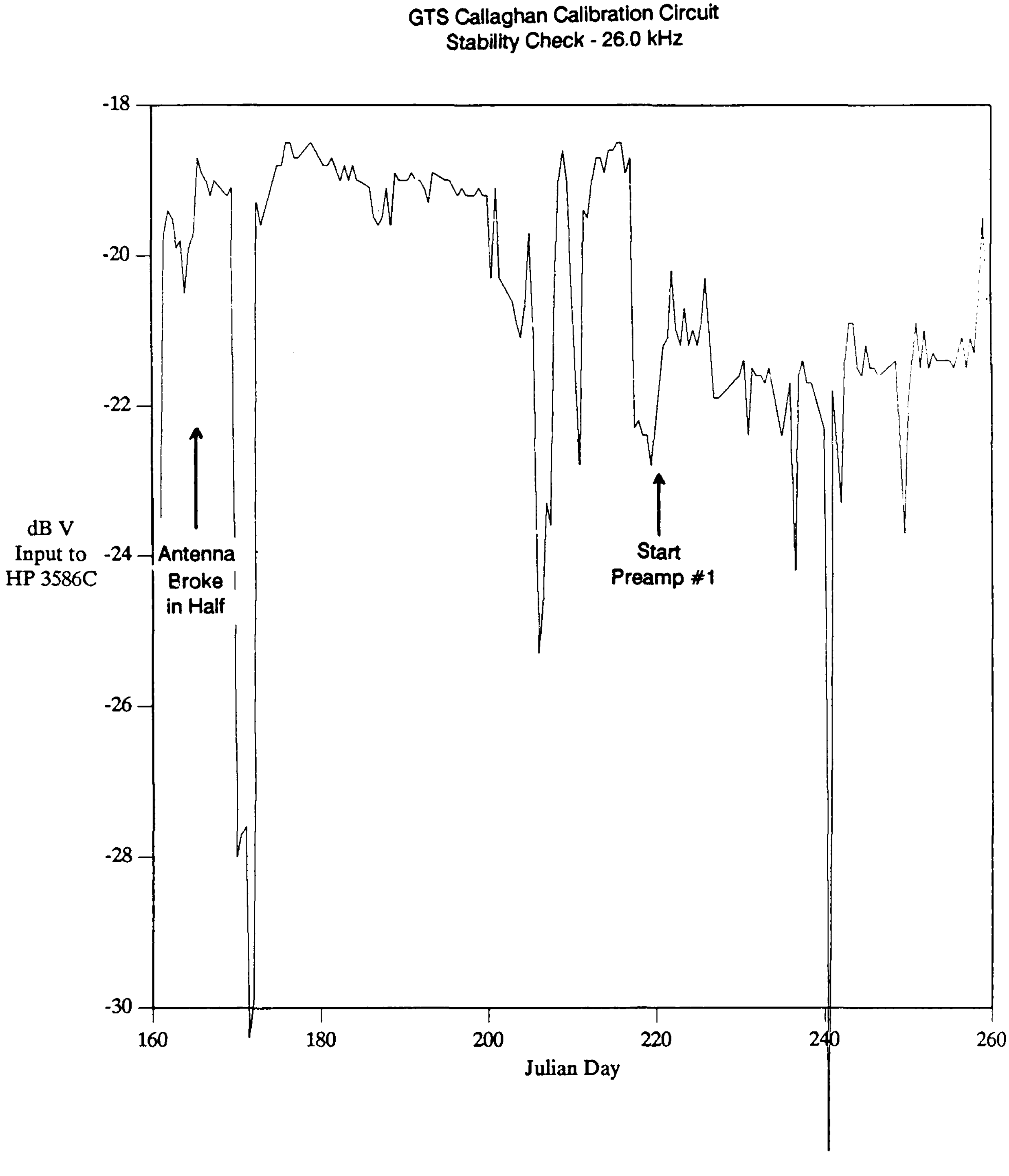
APPENDIX E:
CALLAGHAN PREAMP CALIBRATION STABILITY PLOTS

APPENDIX E

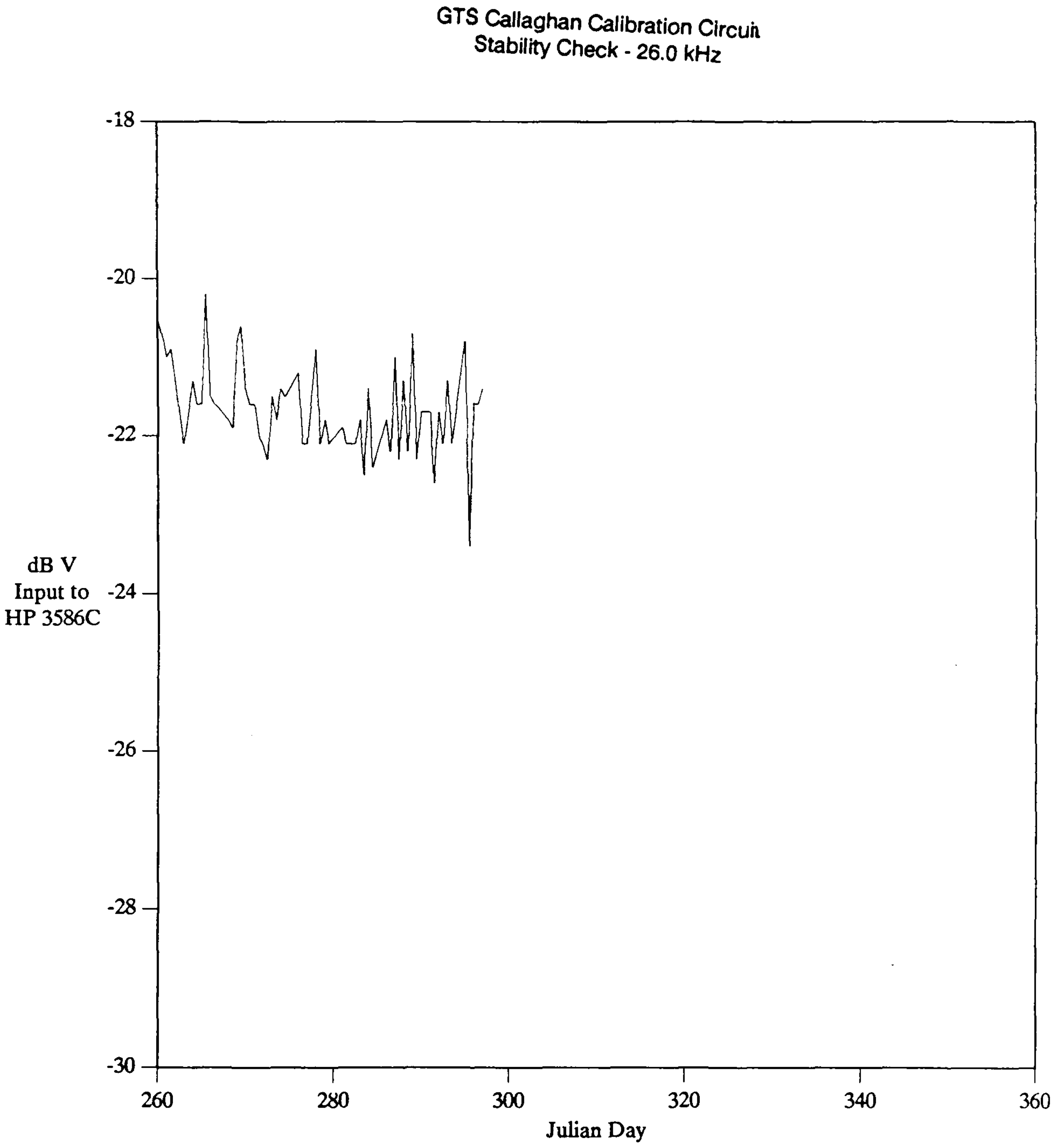
PAGE	FIGURE
1	Callaghan calibration circuit stability check, 26.0 kHz (85060 - 85160)
2	Callaghan calibration circuit stability check, 26.0 kHz (85160 - 85260)
3	Callaghan calibration circuit stability check, 26.0 kHz (85260 - 85300)
4	Callaghan calibration circuit stability check, 63.0 kHz (85300 - 85365)
5	Callaghan calibration circuit stability check, 63.0 kHz (86000 - 86100)
6	Callaghan calibration circuit stability check, 63.0 kHz (86100 - 86200)

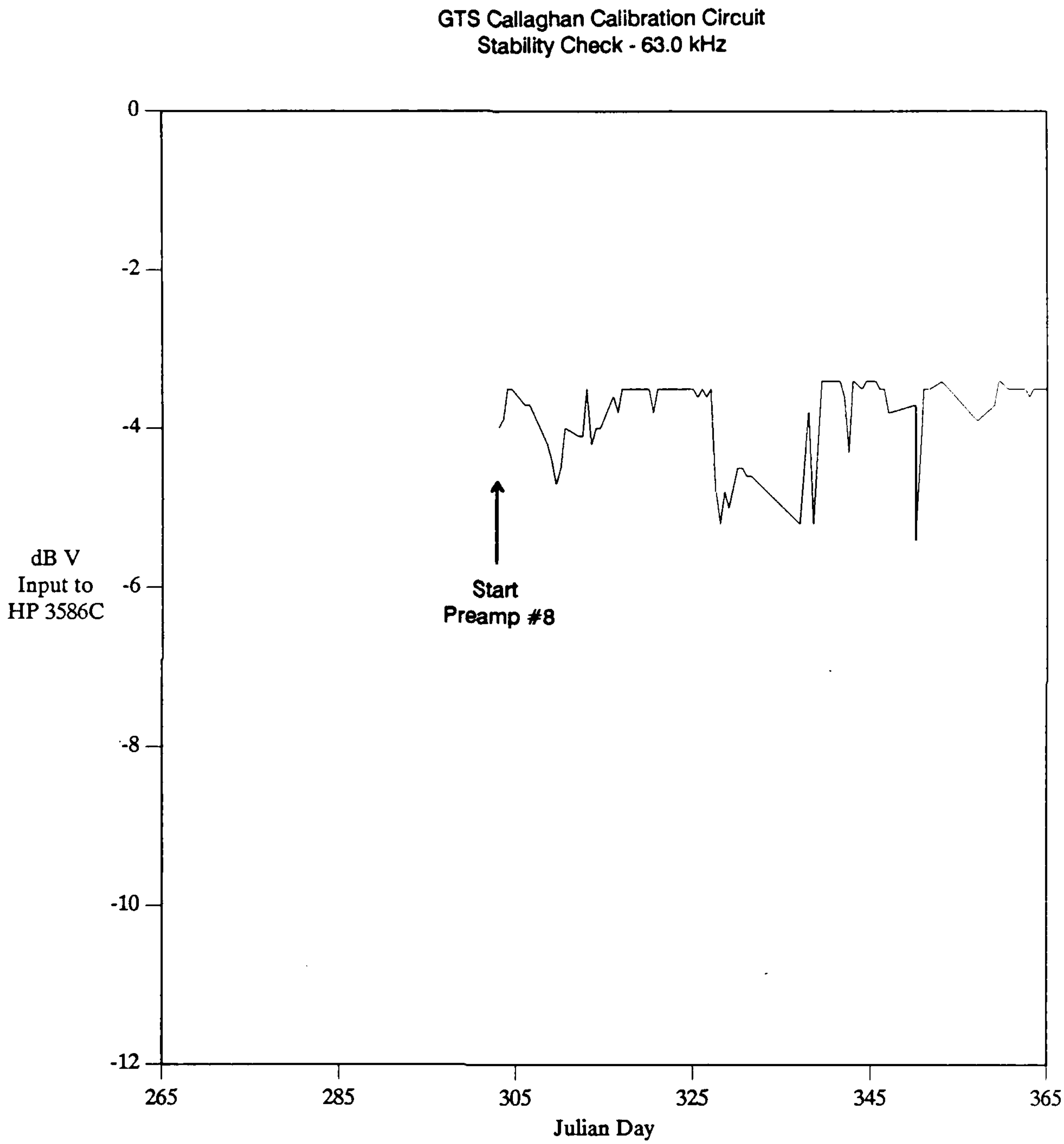
GTS Callaghan Calibration Circuit
Stability Check - 26.0 kHz



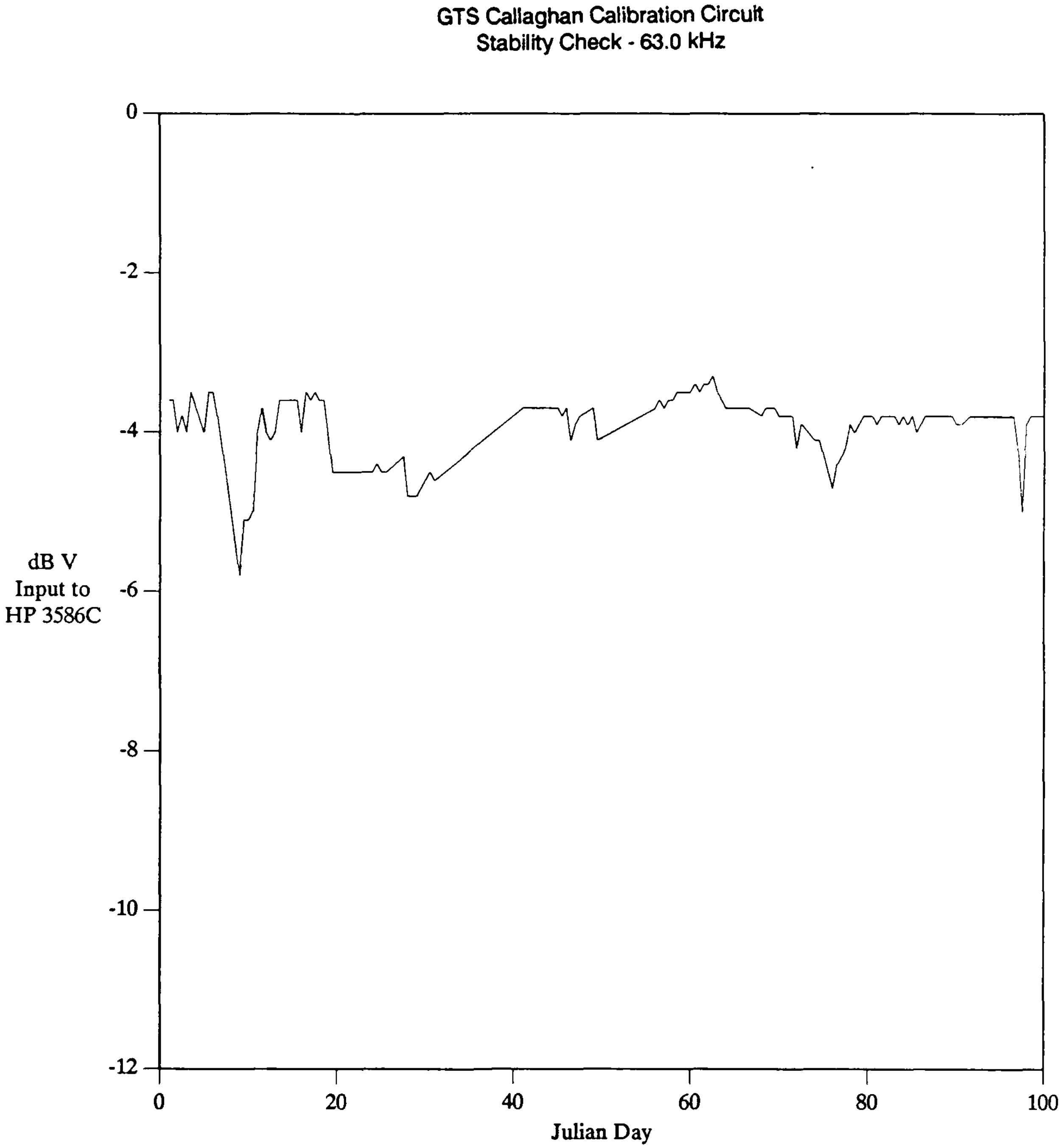


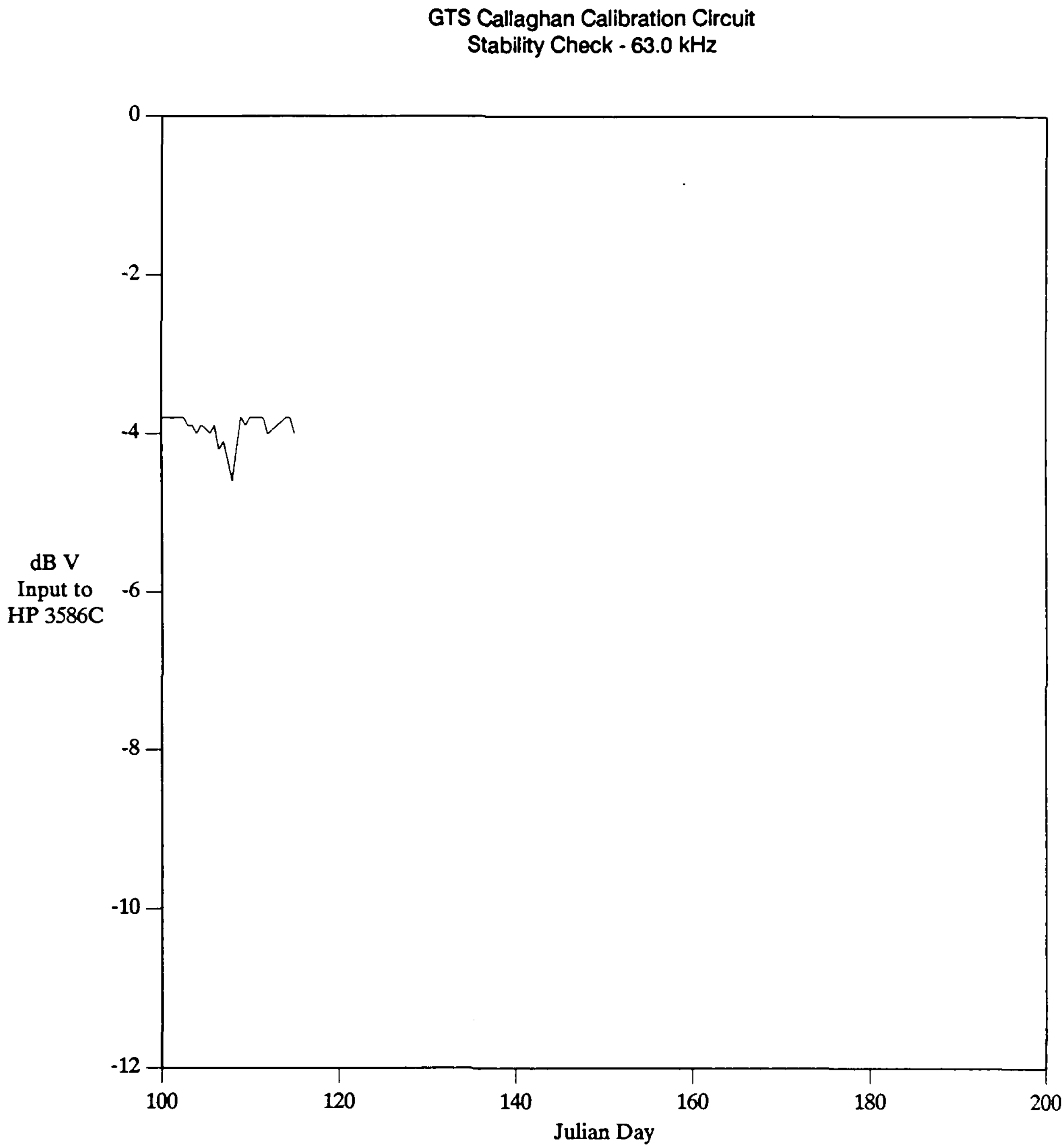
GTS Callaghan Calibration Circuit
Stability Check - 26.0 kHz
-18
-20
-22
-24
-26
-28
-30
dB V
Input to
HP 3586C
Antenna
Broke
in Half
Start
Preamp #1
160
180
200
220
240
260
Julian Day


GTS Callaghan Calibration Circuit
Stability Check - 26.0 kHz
dB V
Input to
HP 3586C
-18
-20
-22
-24
-26
-28
-30
260
280
300
320
340
360
Julian Day



GTS Callaghan Calibration Circuit
Stability Check - 63.0 kHz
0
-2
-4
-6
-8
-10
-12
dB V
Input to
HP 3586C
Start
Preamp #8
265
285
305
325
345
365
Julian Day


GTS Callaghan Calibration Circuit
Stability Check - 63.0 kHz
0
-2
-4
-6
-8
-10
-12
dB V
Input to
HP 3586C
0
20
40
60
80
100
Julian Day


GTS Callaghan Calibration Circuit
Stability Check - 63.0 kHz
dB V
Input to
HP 3586C
0
-2
-4
-6
-8
-10
-12
100
120
140
160
180
200
Julian Day

APPENDIX F:
VLF/LF NOISE
DATA

Appendix F is Included With Volume 2

of the

GTS Callaghan/C-141 VLF/LF Data 1984-1986

Report

Volume 2 is available on request from:
Naval Ocean Systems Center
271 Catalina Blvd
San Diego, CA 92152
CODE 542
619-553-3056

APPENDIX G:
C-141 VLF/LF
SIGNAL DATA

Appendix G is Included With Volume 2

of the

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San Diego, CA 92152
CODE 542
619-553-3056

APPENDIX H:
GTS CALLAGHAN VLF/LF
SIGNAL DATA

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619-553-3056